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AL/XPPL ltr., 5 Feb 1997

(12)

Report USAFSAM-TR- 83-27

AD B076 849

THE F-16 ONBOARD OXYGEN GENERATING SYSTEM: PERFORMANCE EVALUATION AND MAN RATING

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August 1983

Final Report for Period 1 March 1982 - 31 December 1982

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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NOTICES

This final report was submitted by personnel of the Crew Systems Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 2761-00-01.

The voluntary informed consent of the subjects used in this research was obtained in accordance with AFR 169-3.

This report has been reviewed and is approved for publication.

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAFSAM-TR-83-27	2. GOVT ACCESSION NO. B076849L	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) THE F-16 ONBOARD OXYGEN GENERATING SYSTEM: PERFORMANCE EVALUATION AND MAN RATING		5. TYPE OF REPORT & PERIOD COVERED Final Report 1 Mar 1982 - 31 Dec 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) T. C. Horch, Capt, USAF; R. L. Miller, Ph.D.; J. B. Bomar, Jr., Lt Col, USAF, BSC; J. B. Tedor, Maj, USAF, BSC; R. D. Holden, B.A.; K. G. Ikels, Ph.D.; P. A. Lozano, B.A.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS USAF School of Aerospace Medicine (VNL) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 63246F 27610001
11. CONTROLLING OFFICE NAME AND ADDRESS USAF School of Aerospace Medicine (VNL) Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE August 1983
		13. NUMBER OF PAGES 58
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government agencies only; test and evaluation; 27 June 1983. Other requests for this document must be referred to AMD/RDO.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Onboard oxygen generator	Hypoxia
Molecular sieve	Oxygen composition controller
Liquid oxygen system	Breathing-gas regulator
Man rating	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An onboard oxygen generating system (OBOGS) has been developed by Clifton Precision, according to U.S. Air Force School of Aerospace Medicine (USAFSAM) specifications, for a flight test demonstration in the F-16A aircraft. Prior to actual flight test, the system was certified at the USAFSAM as described in this report. Laboratory testing consisted of manned and unmanned tests at ground level, at altitude, during rapid decompressions, and during acceleration loading. System hardware consisted of a molecular sieve concentrator, breathing-gas regulator,

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20. ABSTRACT (Continued)

selector valve, product gas composition controller, backup oxygen supply (BOS), and a breathing mask. These components replace current liquid oxygen (lox) components and eliminate the need to service lox converters, resulting in faster aircraft turnaround time, increased safety, and decreased cost. Laboratory test results indicated that the F-16A OBOGS was adequate for flight test and that the breathing-gas compositton was physiologically capable of preventing hypoxia and reducing the occurrence of atelectasis. Furthermore, the OBOGS provided considerably less breathing resistance than current lox systems. The concentrator and BOS provided the ability and redundancy to protect the pilot throughout the operational envelope of the F-16A.

CONTENTS

THE F-16 ONBOARD OXYGEN GENERATING SYSTEM: PERFORMANCE EVALUATION AND MAN RATING

INTRODUCTION

The U.S. Air Force School of Aerospace Medicine (USAFSAM) is developing equipment to replace aircraft liquid oxygen (lox) breathing systems with an onboard oxygen generating system (OBOGS). Prototype OBOG systems have been designed and built in previous research and development efforts. Now USAFSAM is developing a preproduction OBOGS, including hardware development, laboratory testing, and flight testing in an F-16A aircraft. Clifton Precision Instruments and Life Support Division, of Litton Industries, has developed OBOGS hardware according to USAFSAM specifications. USAFSAM conducted laboratory testing before completion of F-16 aircraft modification at General Dynamics and the subsequent flight test at Hill Air Force Base, Utah. This report describes the F-16A OBOGS equipment, laboratory test procedures, and data and results obtained during the OBOGS performance evaluation at USAFSAM. Laboratory testing consisted of a simulated-flight-envelope evaluation of all OBOG subsystems to determine equipment limitations. This was followed by man rating to determine the equipment's ability to sustain human physiological requirements.

SYSTEM DESCRIPTION

Components of the F-16A OBOGS include a concentrator, regulator, oxygen mask and connector, monitor, controller, selector valve, backup oxygen supply (BOS), and indicators (Fig. 1). The system was designed to provide a physiologically acceptable breathing gas for all flight modes of the F-16A aircraft (representative of current USAF high-performance tactical weapon systems). The OBOGS is the primary breathing-gas source for the test aircraft up to 25,000-ft cabin altitude. If cabin depressurization should occur above 25,000 feet, the OBOGS will automatically deliver gaseous aviators' breathing oxygen--MIL-O-27210D, type 1 (99.5% purity)--to the pilot via the backup supply. Descriptions of the individual components follow.

Concentrator

A molecular sieve concentrator is used to produce an oxygen-enriched breathing gas. The concentrator is supplied with engine bleed air from the aircraft environmental control system (ECS). The concentrator (Fig. 2) contains an internal pressure regulator which reduces concentrator inlet pressure to 37.5 ± 5 psig. Engine bleed air is cycled alternately through a pair of molecular sieve beds to produce an oxygen-enriched breathing gas having a maximum oxygen concentration of 95%, with 5% argon. The oxygen concentration depends upon inlet air temperature and pressure, exhaust pressure (altitude), and the rate of product flow demanded from the concentrator. Product gas is supplied to the monitor, controller, shuttle valve,

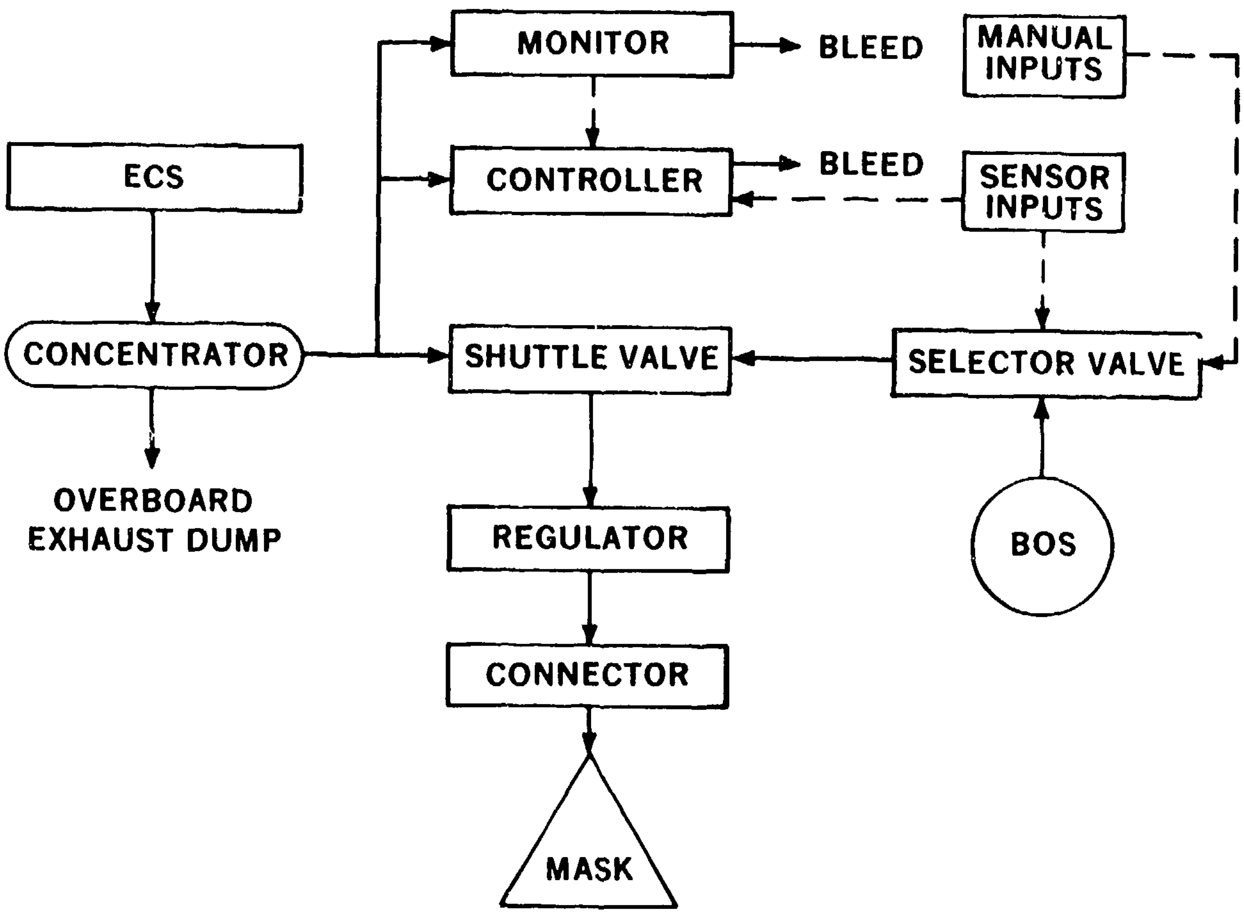

Figure 1. F-16A OBOGS functional diagram.

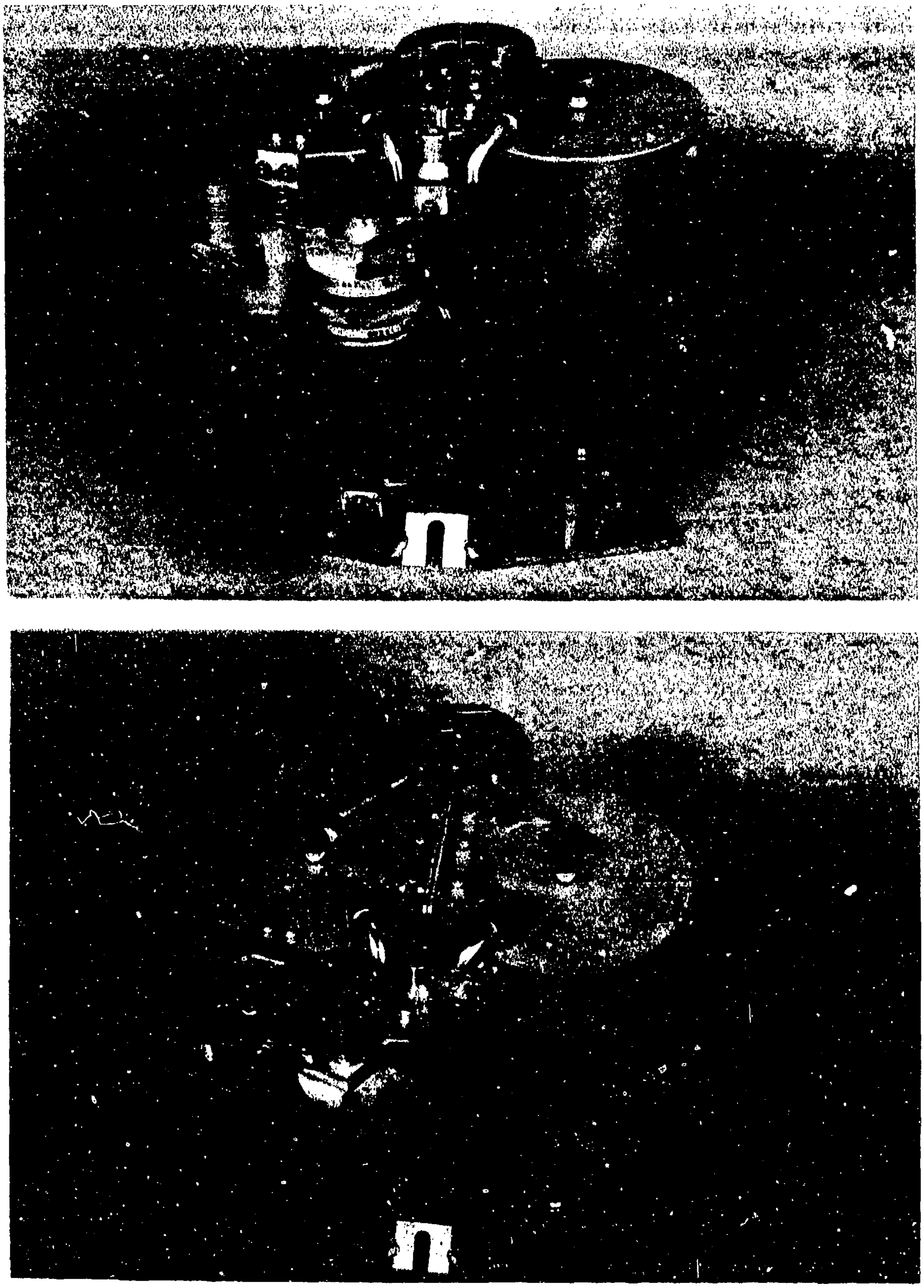

Figure 2. F-16 OBOGS concentrator.

breathing regulator, and mask. A fiberglass shroud encloses the concentrator to reduce heat gain or loss (Fig. 3).

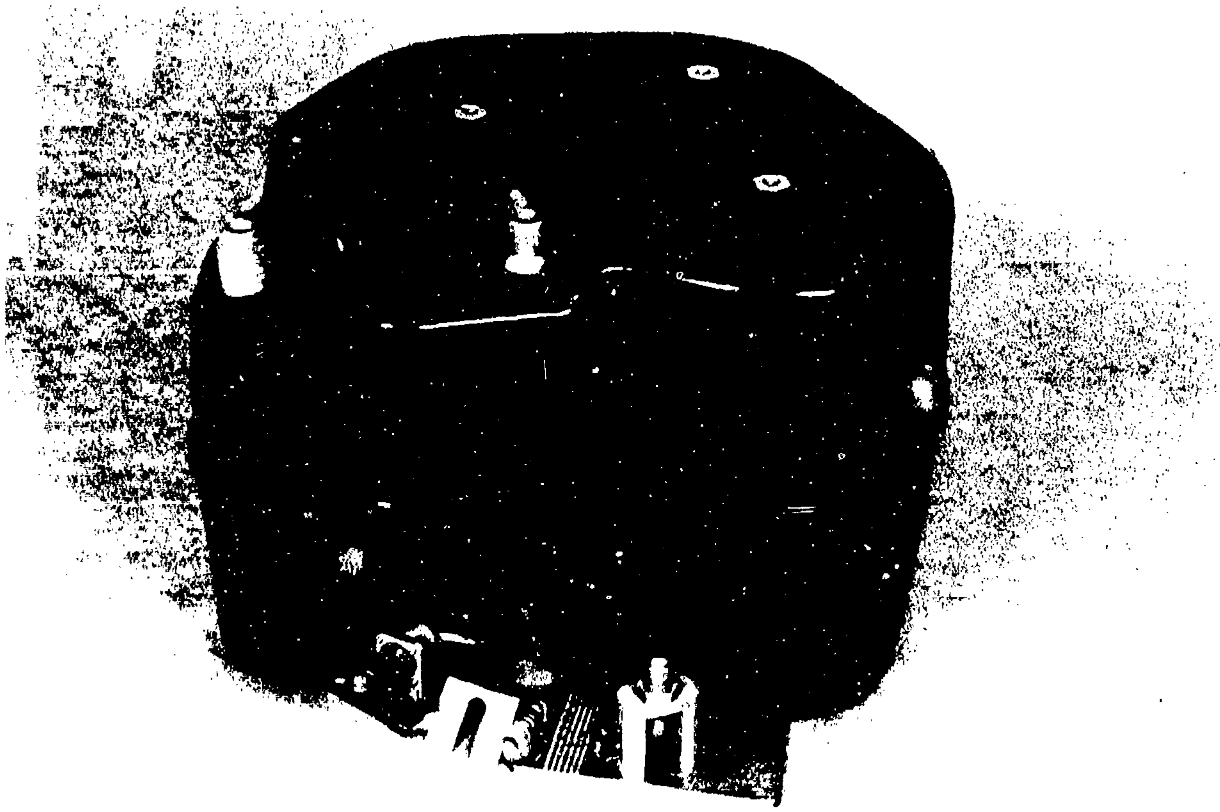

Figure 3. F-16 OBOGS concentrator with shroud.

Regulator

The pilot's breathing-gas regulator reduces inlet gas supply pressure to a level suitable for human respiration. The regulator inlet pressure is approximately 38 psig when the regulator is supplied from the concentrator, and approximately 60 psig when supplied from the BOS. (BOS pressure is reduced from a nominal 1800 psig to 60 psig in the selector valve.) The regulator provides a positive static safety pressure of approximately 1 inch-water-gauge (in-wg) at all cabin altitudes up to 38,000 feet. At 38,000-ft cabin altitude, a pressure breathing feature delivers an increased positive pressure schedule to the mask. The regulator is a 100% pressure demand regulator and does not dilute the breathing gas with cabin air. A press-to-test button on the regulator provides 17-in-wg pressure to the mask-to-test mask fit.

Connector and Mask

The OBOGS includes a standard USAF CRU-60/P connector as well as standard oxygen hoses. A modified United Kingdom type P/Q aviation oxygen mask and the USAF MBU-5/P or 12/P masks will be used in the flight test demonstration. The P/Q mask is preferred by USAFSAM because of its reduced breathing resistance when compared to the standard MBU 5/P or 12/P mask. Resistance to breathing is less in the P/Q mask because it has separate inspiratory and expiratory valves versus a combined valve in the MBU masks. For this flight demonstration, the P/Q mask was modified to be compatible with USAF communication systems and to allow the mask to be attached to the standard USAF HGU-26/P helmet with bayonet receivers.

Monitor

The OBOGS incorporates a polarographic-type oxygen monitor to measure the partial pressure of oxygen (PO_2) produced by the concentrator. This monitor provides a low-oxygen warning to the pilot and automatically activates the BOS if the concentrator is producing an insufficient oxygen partial pressure. The monitor's output is an adjustable electrical signal which is linearly proportional to PO_2. This signal is compared with an internally generated reference voltage. When the monitor output falls below the reference voltage, a binary signal is generated which activates the BOS and illuminates an OXY LOW caution light. The reference voltage and monitor gain are adjusted to activate the BOS and to illuminate the indicator lights whenever the concentrator product gas PO_2 falls below 195 mmHg. A system press-to-test button on the regulator activates a test of the monitor and automatic switchover to BOS. When the test is activated, ambient cabin air is delivered to the monitor and produces a low PO_2 condition. When the press-to-test is released, OBOGS product gas is delivered to the monitor and bleeds overboard through the monitor case.

Controller

The OBOGS incorporates a controller to adjust the product gas composition. Product gas oxygen concentration should be no greater than 70% from ground level to 17,000-ft cabin altitude. The product gas composition is controlled by bleeding a prescheduled amount of product gas into the cabin. The amount of gas (product bleed flow) bled into the cabin is a function of cabin altitude and is also affected by the amount of product gas delivered to the crewmember. The controller is strictly a pneumatic device and does not incorporate feedback from the oxygen monitor.

Selector Valve

The OBOGS selector valve is used to manually and/or automatically select the breathing-gas source from either the OBOGS concentrator or the BOS. The selector valve has four positions: OFF, OBOG, NORMAL AUTO, and BACKUP OXY. In this report these will be referred to as OFF, OBOG, AUTO, and BU respectively. The crewmember can at any time manually select backup oxygen by placing the selector valve at BU. With the valve in this position, stored oxygen from the backup supply will be delivered through the shuttle valve and regulator to the mask. With the selector valve at OFF, the BOS bottles are mechanically locked out and cannot supply the regulator. The OFF position allows the system test to be completed without depleting the BOS and also inactivates the BOS when the concentrator or aircraft engine is not operating. With the selector valve at AUTO, the system will automatically switch to BOS if the OBOGS product-gas oxygen partial pressure falls below 195 mmHg or if cabin altitude exceeds 25,000 feet. With the selector valve at OBOG, below 31,000-ft cabin altitude the pilot can manually reselect OBOGS product gas. Above 31,000 feet, the system automatically reselects the BOS. With the selector valve set at either OBOG or AUTO, the system will select BOS whenever regulator inlet pressure is less than 10 psig. When the BOS is supplying the regulator, the shuttle valve will pneumatically switch back to OBOG product gas when the BOS bottles are depleted.

Backup Oxygen System

The backup oxygen system consists of two 50-in^3 high-pressure (2000 psig) gaseous oxygen cylinders having a combined capacity of 200 liters NTP (normal temperature and pressure). The two bottles are connected in parallel with the necessary fittings to allow ground filling. A high-pressure hose connects the BOS bottles to the selector valve which reduces the pressure to 60 psig and delivers backup oxygen to the regulator when selected.

Indicators

An oxygen pressure gauge (bailout-bottle type) indicates the pressure remaining in the BOS, and a yellow caution light mounted on the selector valve indicates when the selector valve is in the BU position. This light also illuminates if the cabin altitude is above 31,000 feet (at this altitude the system automatically selects BOS) or if the selector valve is in the AUTO position and a system malfunction causes automatic switchover to the BOS. An OXY LOW caution light illuminates whenever the oxygen monitor detects less than 195-mmHg PO_2 or whenever OBOGS product pressure falls below 10 psig. Illumination of the OXY LOW light also causes the resettable aircraft master caution light to illuminate. The system press-to-test button causes both the OXY LOW and selector valve lights to illuminate. A cockpit-mounted power switch controls electrical power to the concentrator and activates the rotating inlet valve.

PERFORMANCE EVALUATION

The OBOGS was evaluated to determine system characteristics and operating limitations. Concentrator inlet pressure and temperature, exhaust pressure (altitude), and product flow were varied while product gas composition and pressure were measured. Rapid decompression and acceleration testing were also accomplished. A description of the tests and test results follow.

Concentrator

The OBOGS concentrator was tested as a separate component to ascertain its performance characteristics. A pressurized air supply was plumbed through a circulation heater to the concentrator inlet port. The concentrator was located inside an "aircraft-altitude" chamber and was instrumented to monitor/record inlet air temperature, pressure, and flow; exhaust temperature; electrical motor current; and temperature inside the concentrator's shroud. The concentrator exhaust gas was vented to this chamber while product gas was plumbed through actual F-16 oxygen system tubing to an adjoining "cabin-altitude" chamber. A digital controller was used to control the two altitude chambers so that the concentrator would be maintained at aircraft altitude with the product gas vented to cabin altitude. The altitude chambers were controlled to mimic the aircraft pressurization schedule. A metering valve at the end of the concentrator product gas line controlled output flow, and instrumentation recorded product gas composition, flow, and temperature.

A series of ground-level tests were made to determine product gas composition as a function of concentrator inlet pressure and outlet flow. Figure 4 illustrates the relationship between concentrator inlet pressure and product gas composition at a steady product flow of 20 l/min and with concentrator inlet air at ambient temperature (23°, or 73°F). The oxygen, nitrogen, and argon curves tend to flatten out above 40-psig inlet pressure due to the concentrator's internal pressure regulator. Note that oxygen concentration is considerably lower with low inlet pressures; however, this should not present a problem in the F-16 because minimum inlet pressure is expected to be 40 psig. Figure 5, except for product flow of 50 l/min, is similar to Figure 4. Figure 6 displays oxygen concentration as a function of concentrator inlet pressure and product flow. This curve (ground level) was obtained with ambient inlet temperature and shows product flow curves for 20, 50, and 100 l/min. Higher product flows decrease the oxygen concentration in the product gas. Figure 7 is a plot of product gas composition versus product gas flow. This data was obtained at ground level with the inlet pressure set at 40 psig and with inlet air at ambient temperature.

At this time it is advantageous to explain some terminology that will be used throughout the remainder of this report. Concentrator inlet pressure was always gauge pressure referenced to aircraft (concentrator) altitude. Thus, at ground level, 40 psig inlet pressure was 40+14.4, or 54.4 psia (absolute); and at 10,000-ft aircraft altitude, 40 psig inlet pressure was 40+10.1, or 51.1 psia; and product flows were ATPD (ambient temperature, pressure, dry) liters per minute. Therefore, a product flow of 50 l/min at 10,000 feet was equivalent to a ground-level flow of 50X (10.1/14.4), or 35.1 l/min.

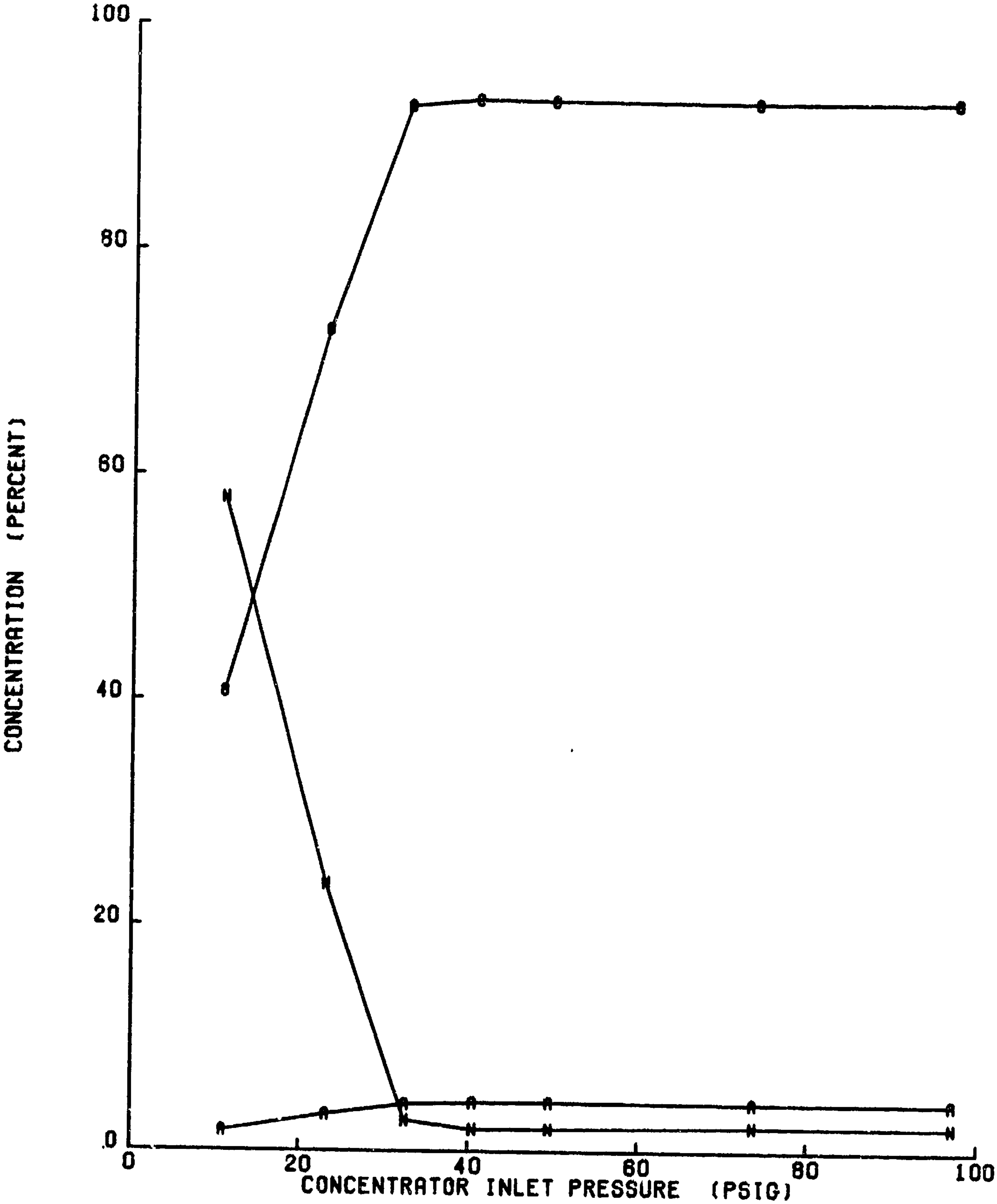

Figure 4. OBOGS concentrator only: product gas composition vs concentrator inlet pressure, at ground level, with 20-l/min product flow and 23°C inlet temperature. (O = oxygen, N = nitrogen, A = argon)

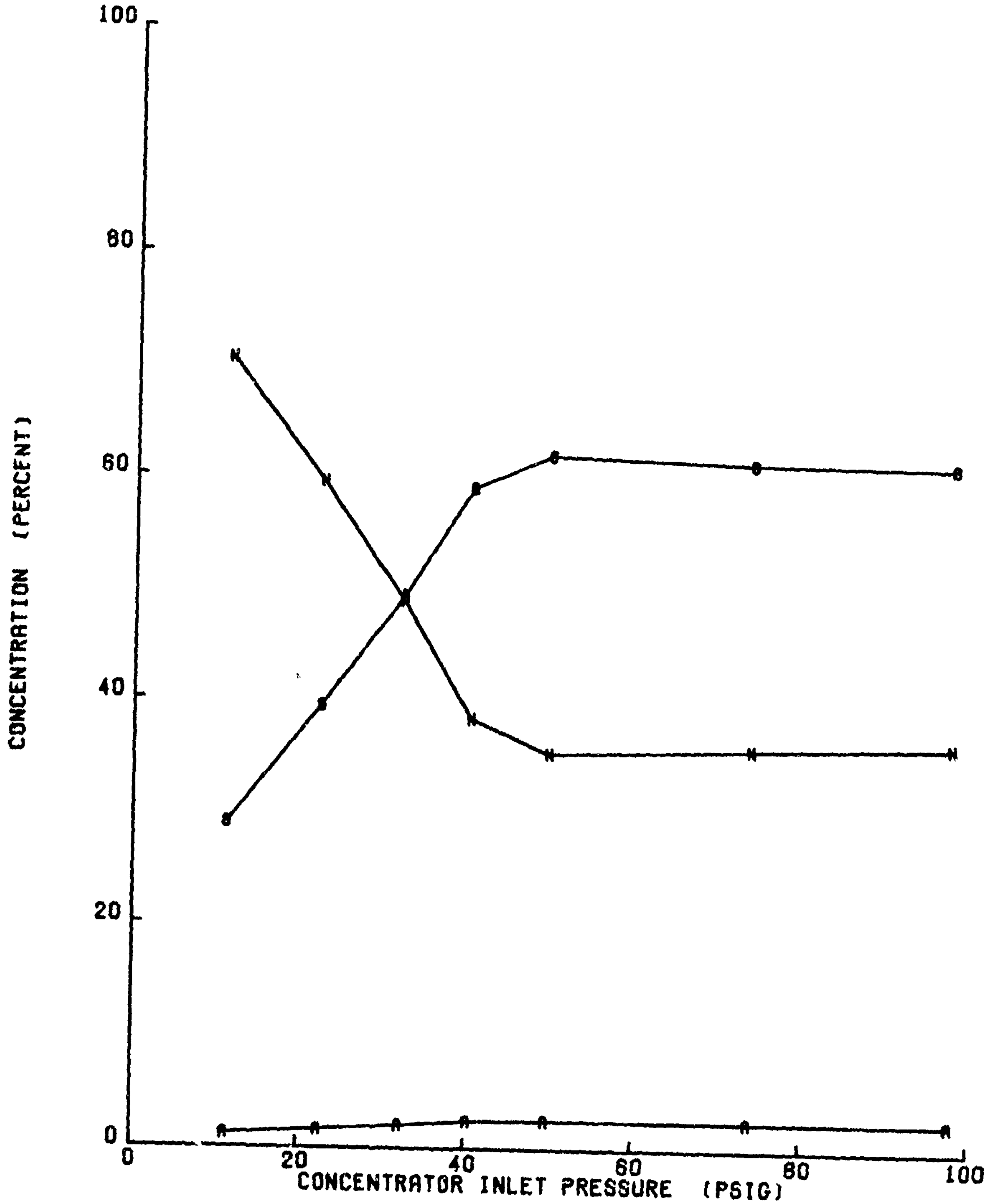

Figure 5. OBOGS concentrator only: product gas composition vs concentrator inlet pressure, at ground level, with 50-l/min product flow and 23°C inlet temperature. (O = oxygen, N = nitrogen, A = argon)

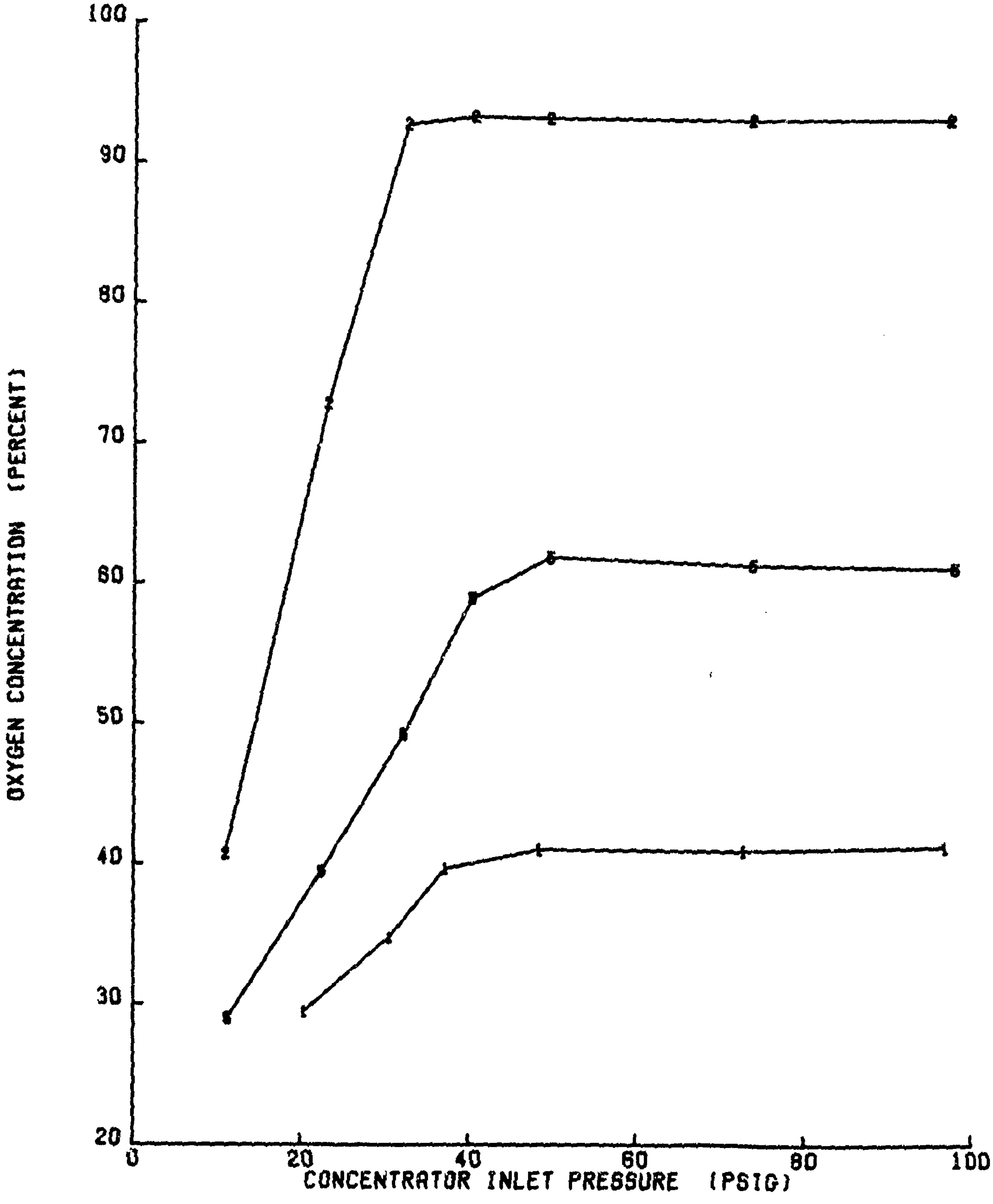

Figure 6. OBOGS concentrator only: oxygen concentration vs concentrator inlet pressure, at ground level, with 23°C inlet temperature and product flows of 20, 50, and 100 l/min. (2 = 20, 5 = 50, 1 = 100 l/min)

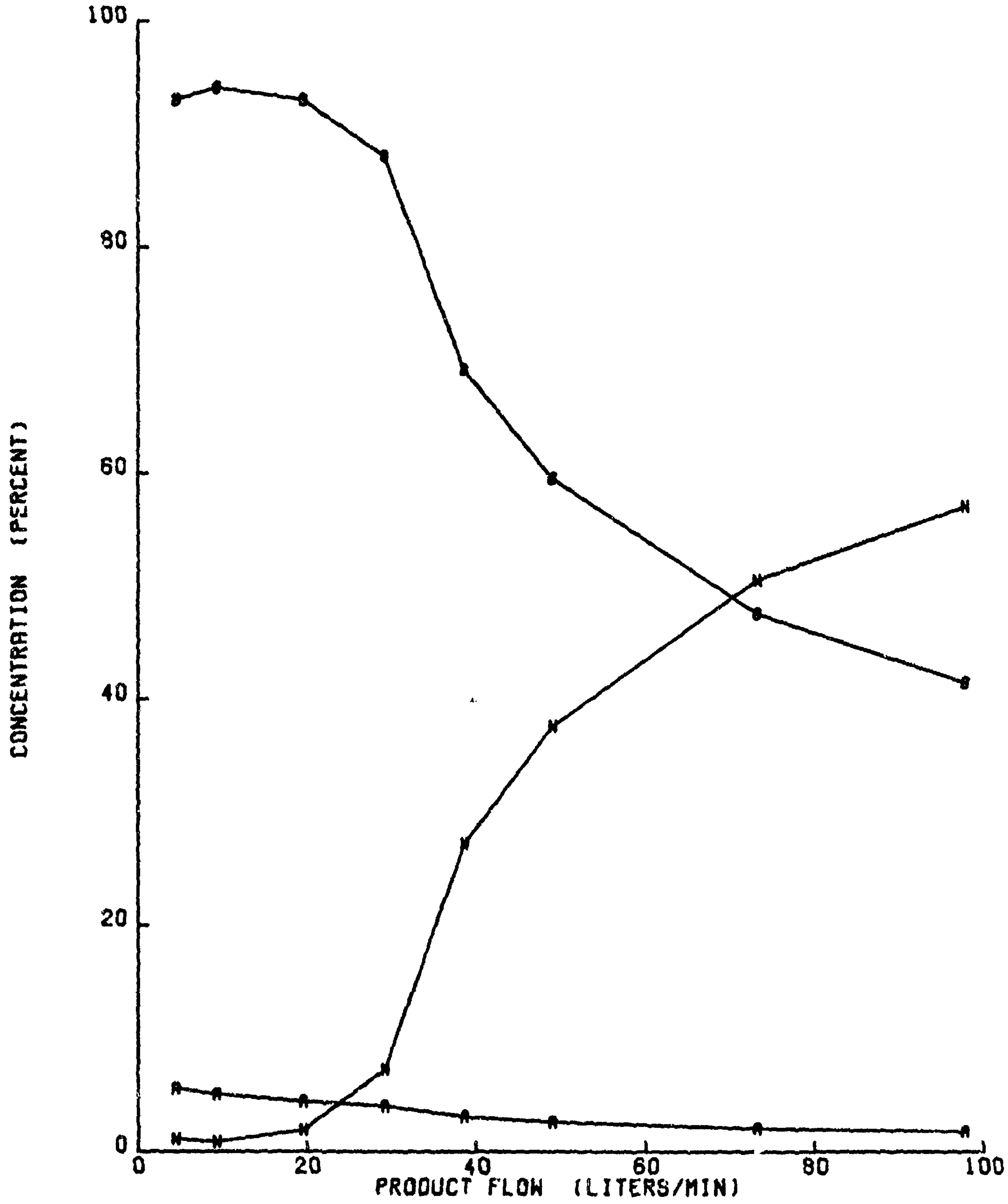

Figure 7. OBOGS concentrator only: product gas composition vs product flow at ground level, with 23°C inlet temperature and 40-psig inlet pressure. (O = oxygen, N = nitrogen, A = argon)

Oxygen concentration increased with increasing altitude, as shown in Figure 8, for the higher product flow of 50 l/min ATPD. This data was obtained with a constant inlet pressure of 40 psig and with inlet air at ambient temperature. As aircraft altitude increased, cabin altitude increased according to the F-16 aircraft pressurization schedule: normobaric altitudes are maintained to 8,000 feet; the cabin maintains an isobaric altitude of 8,000 feet while the aircraft climbs to 23,000 feet; and above 23,000 feet the cabin maintains a 5 psi differential above ambient pressure. Except for simulating an unpressurized cabin (equal aircraft and cabin altitudes), Figure 9 is similar to Figure 8.

The remaining variable that affected product composition was heat. The primary source of heat in the F-16 is heat of compression in the engine bleed air. Engine bleed air in the F-16 is conditioned by the aircraft environmental control system; however, concentrator inlet air temperature remains elevated above ambient outside-air temperature. Aircraft installation was simulated in the laboratory by heating the inlet air temperature and allowing the concentrator to reach equilibrium, as determined by monitoring exhaust temperature and temperature inside the concentrator shroud.

The ground-level effect of temperature on product composition is shown in Figure 10. This data was obtained with concentrator inlet pressure of 40 psig and indicates that oxygen concentration was lower at 80°C (176°F) than at 23°C ambient inlet air temperature. Figure 11 shows the ground-level relationship between oxygen concentration and concentrator inlet pressure with 80°C inlet air.

The oxygen concentration at altitude is shown in Figure 12 for three product flows--20, 50, and 100 l/min; inlet temperature was 80°C and concentrator inlet pressure, 40 psig. Figure 13 compares oxygen concentration at altitude for 20 and 80°C inlet air with a steady product flow of 50 l/min.

After concentrator performance was determined, the cockpit-mounted components were added to obtain system performance.

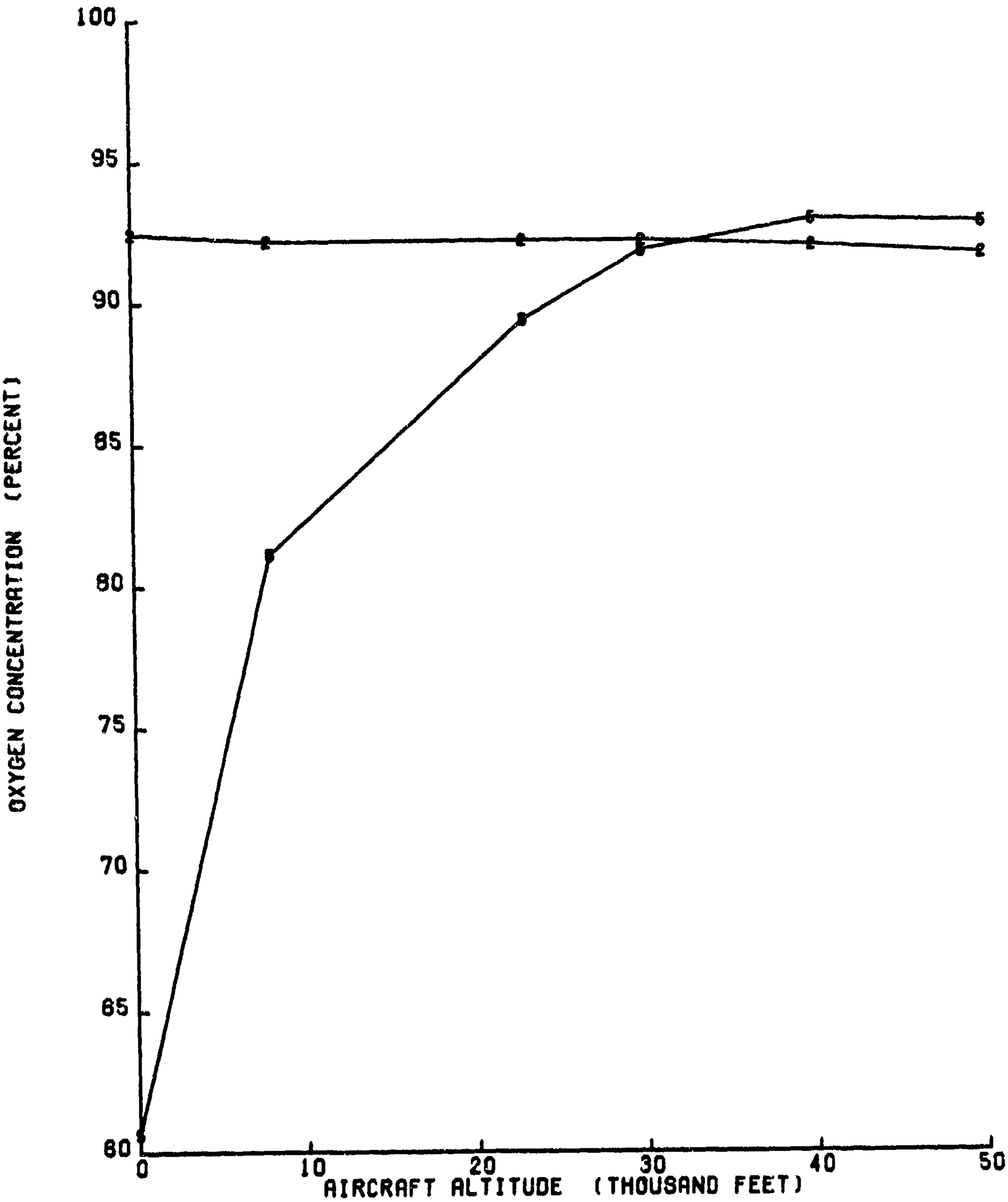

Figure 8. OBOGS concentrator only: oxygen concentration vs pressurized aircraft altitude, with 23°C inlet temperature, 40-psig inlet pressure, and product flows of 20 and 50 l/min. (2 = 20, 5 = 50 l/min)

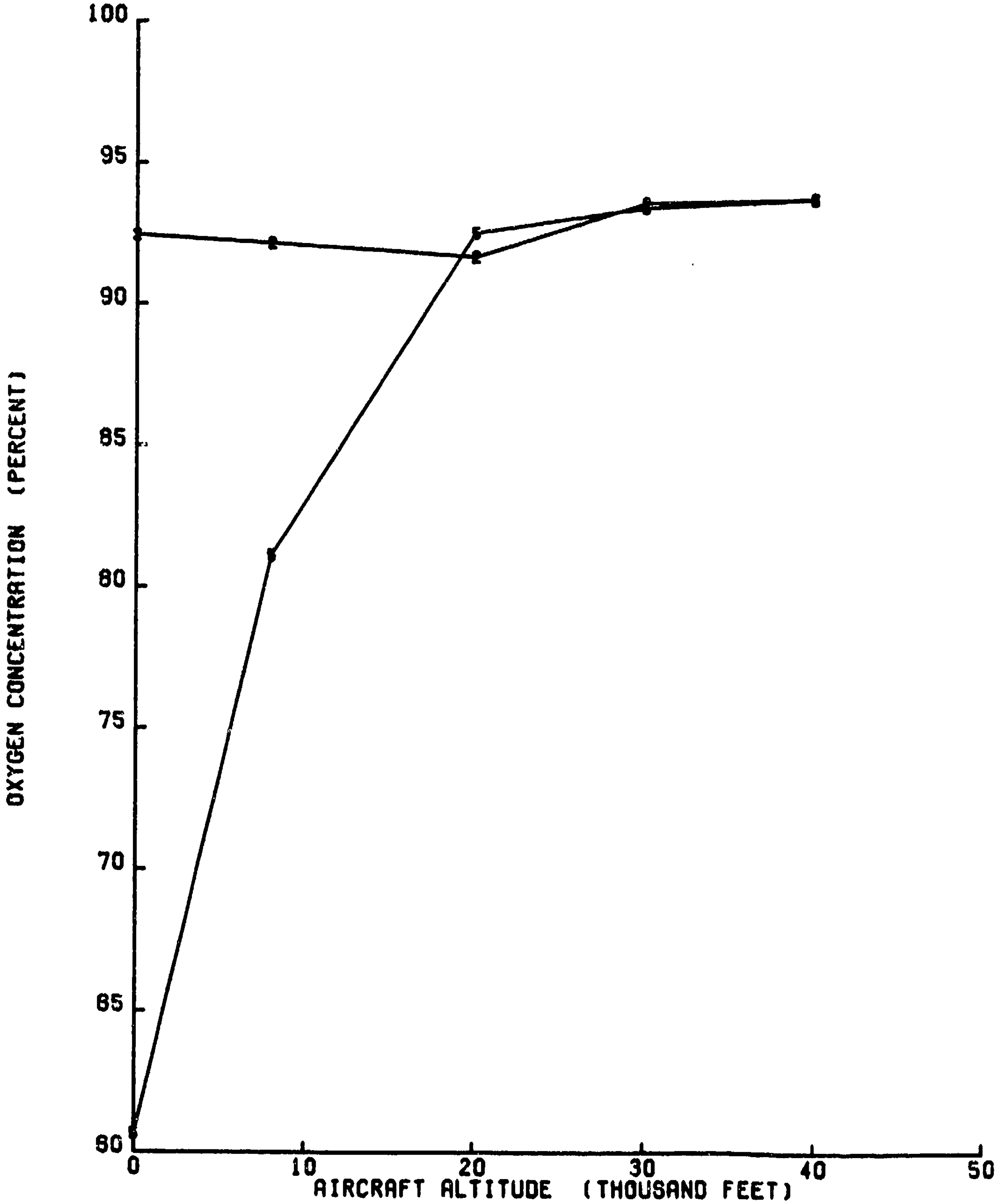

Figure 9. OBOGS concentrator only: oxygen concentration vs unpressurized aircraft altitude, with 23°C inlet temperature, 40-psig inlet pressure, and product flows of 20 and 50 l/min. (2 = 20, 5 = 50 l/min)

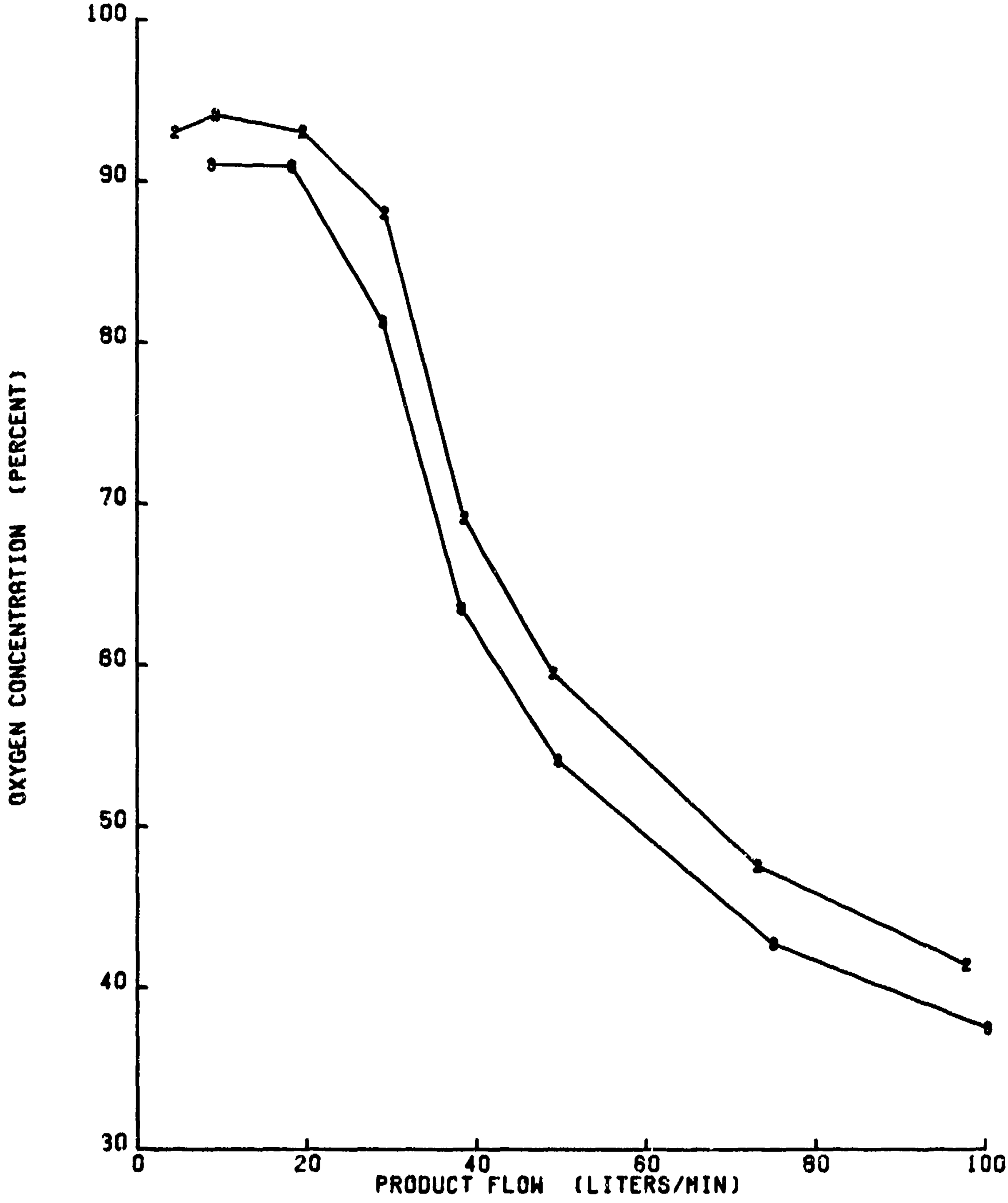

Figure 10. OBOGS concentrator only: oxygen concentration vs product flow, at ground level, with 40-psig inlet pressure and 23 and 80°C inlet temperatures. (2 = 23, 8 = 80°C)

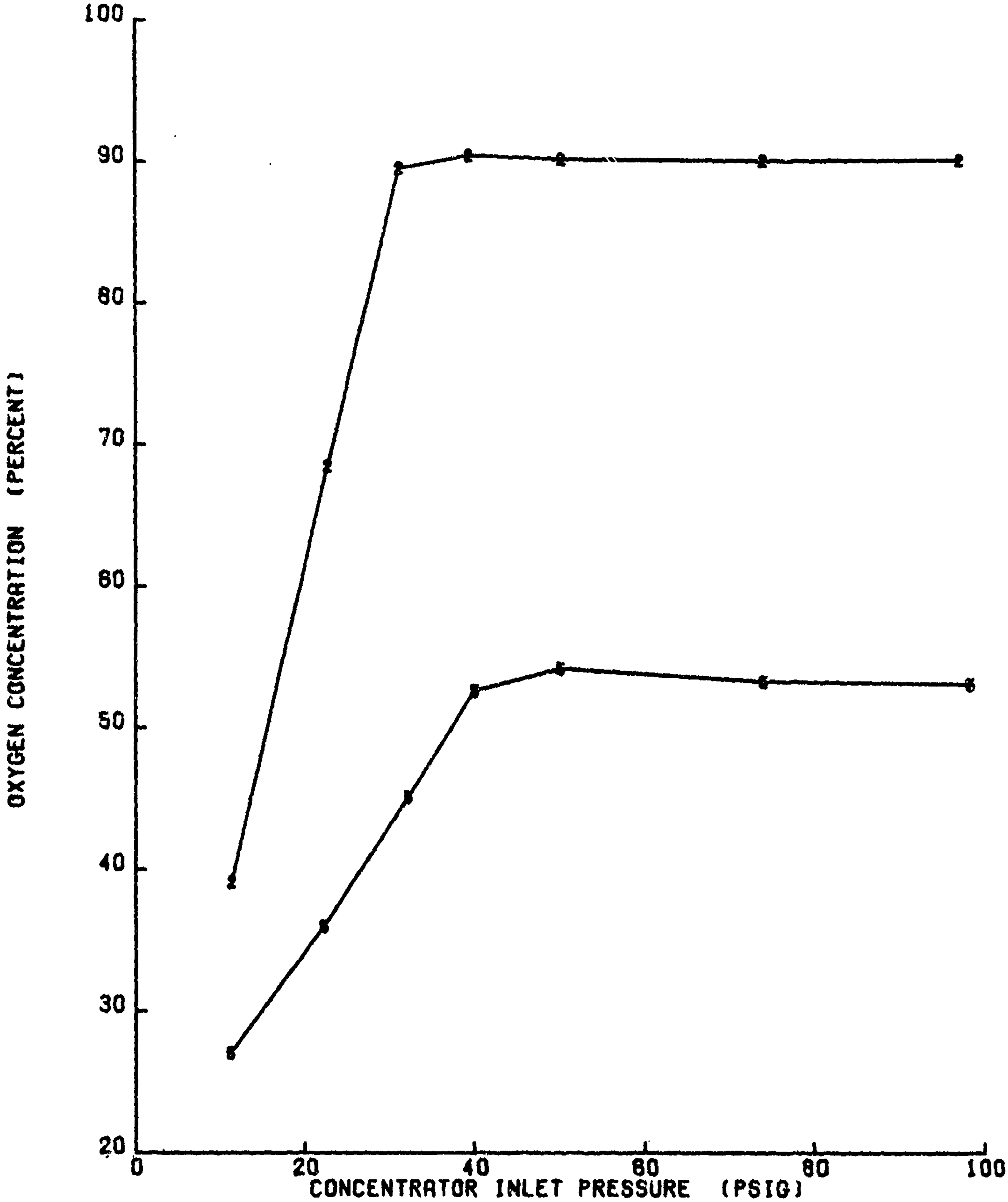

Figure 11. OBOGS concentrator only: oxygen concentration vs inlet pressure, at ground level, with 80°C inlet temperature and product flows of 20 and 50 l/min (2 = 20, 5 = 50 l/min)

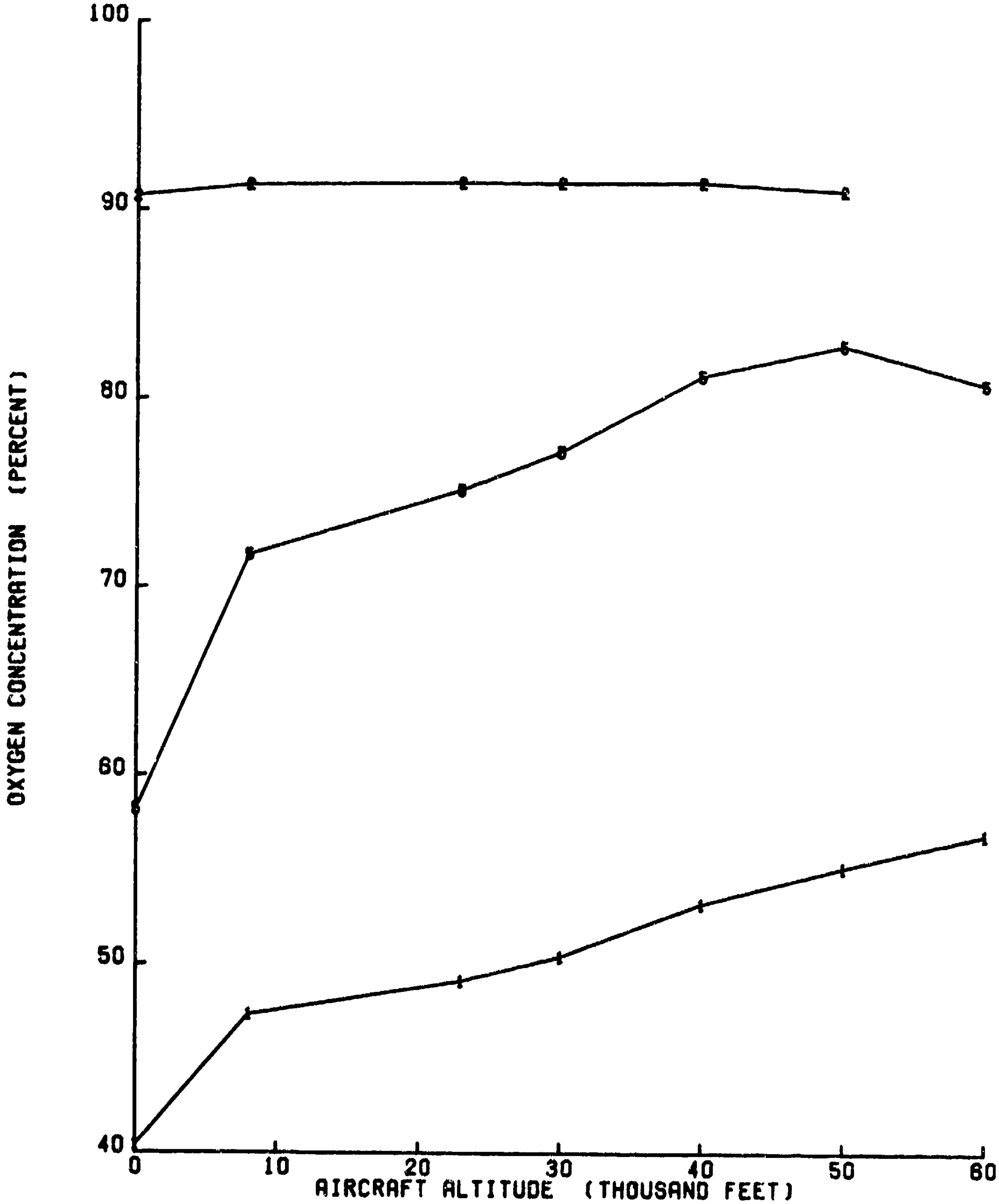

Figure 12. OBOGS concentrator only: oxygen concentration vs pressurized aircraft altitude, with 80°C inlet temperature, 40-psig inlet pressure, and product flows of 20, 50, and 100 l/min. 2 = 20, 5 = 50, 1 = 100)

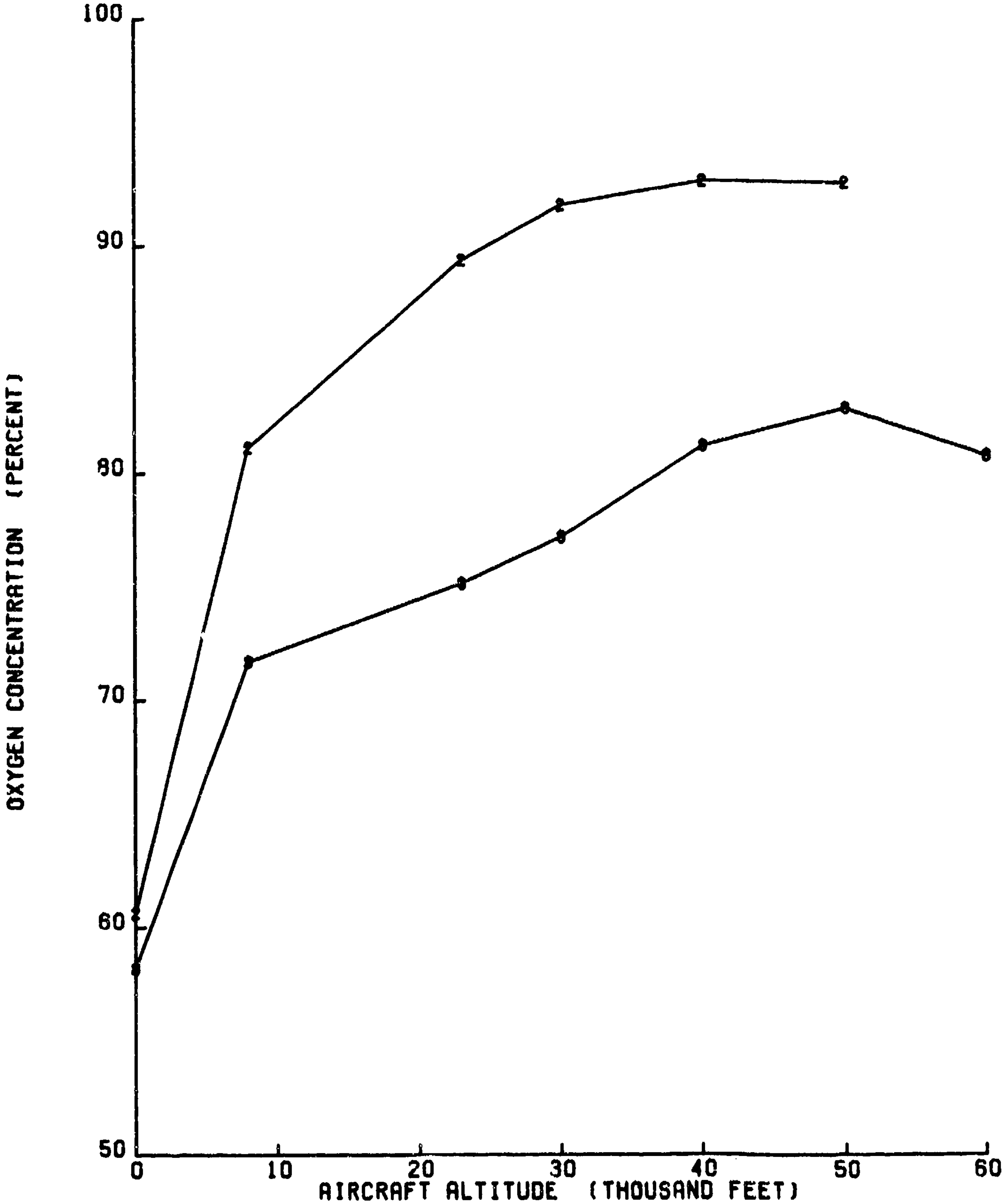

Figure 13. OBOGS concentrator only: oxygen concentration vs pressurized aircraft altitude, with 40-psig inlet pressure, 50-l/min product flow, and inlet temperatures of 23 and 80°C. (2 = 23, 8 = 80°C)

Controller

The OBOGS controller adjusts product gas composition by bleeding product gas into the cabin at a prescheduled rate. Therefore, total concentrator product flow was the sum of pilot inspiratory flow plus controller bleed flow. Figure 14 illustrates the desired oxygen concentration band: The minimum concentration as 195 mmHg, which is above the physiological equivalent to breathing air at sea level, and the maximum concentration was intended to prevent or minimize the occurrence of acceleration-induced atelectasis. Figure 14 also shows the concentration that would be delivered to the pilot with minute volume flows of 10 and 50 l/min at an inlet temperature of 80°C, an inlet pressure of 40 psig, and no controller bleed flow.

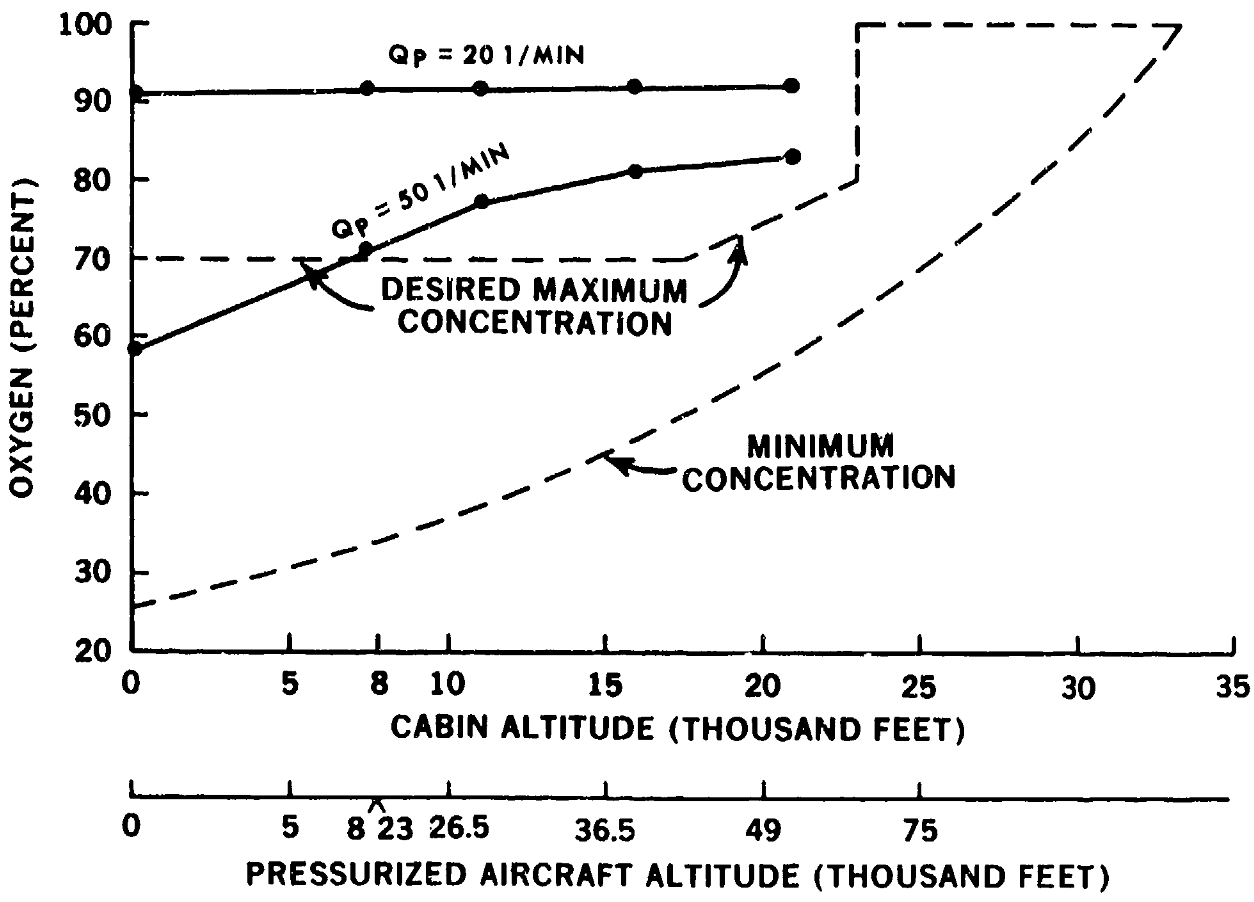

Figure 14. Desired concentration range and OBOGS uncontrolled output vs altitude with product flows (Qp) of 20 and 50 l/min.

USAFSAM personnel had the opportunity to adjust three controllers during laboratory testing. For reference purposes, one will be called the USAFSAM controller (used by USAFSAM for system testing); one, the aircraft controller; and the third, the spare aircraft controller. When the USAFSAM controller was added, bleed flow lowered the oxygen concentration as shown in Figure 15. Here the product flows were 10 and 50 l/min (the approximate minimum and maximum minute volumes expected in flight), the concentrator inlet pressure was 40 psig, and inlet temperature was 80°C. The controller was set to bleed approximately 33.5 l/min at ground level. As altitude increased, bleed flow increased to approximately 70 l/min at 12,000-ft cabin altitude, then began to decrease, and stopped completely at 22,000-ft cabin altitude.

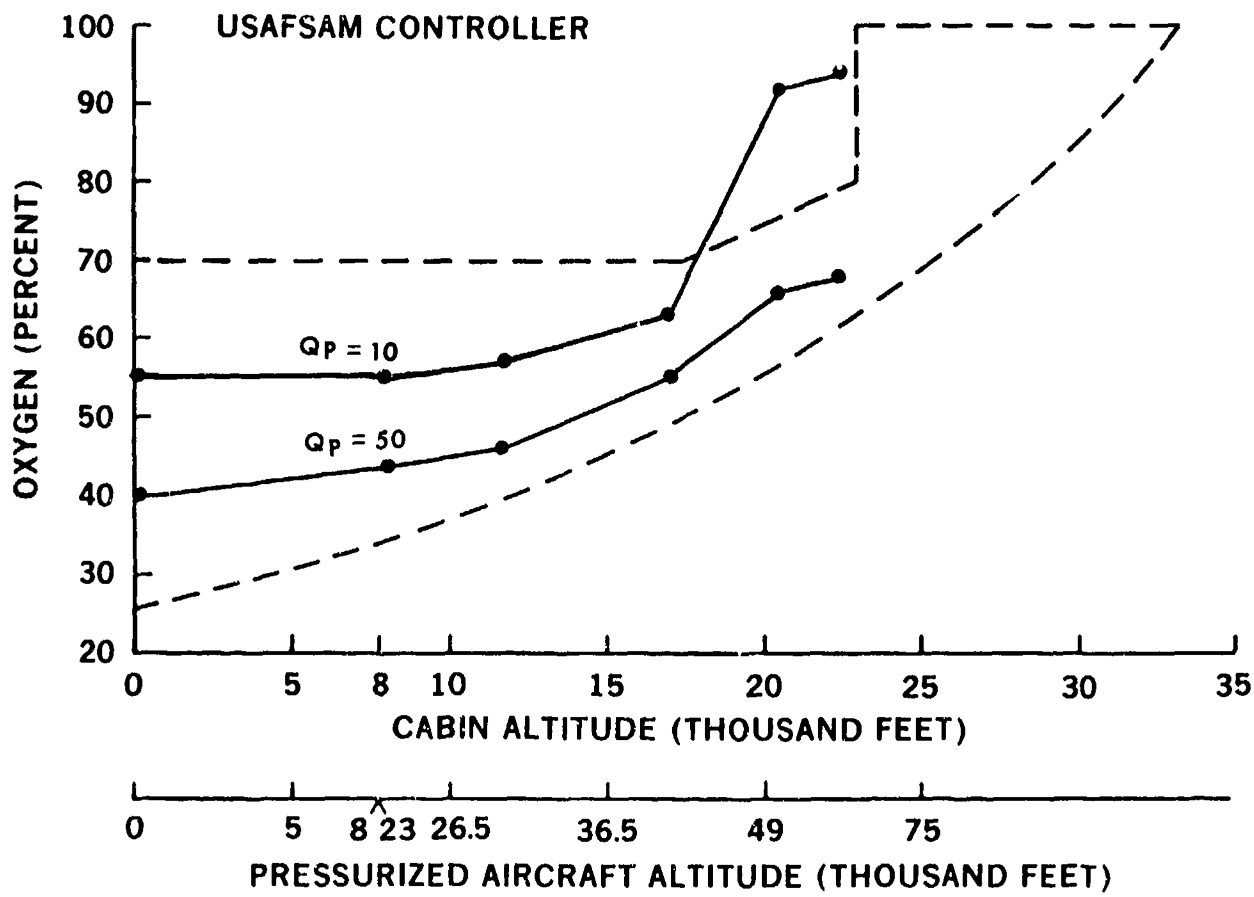

Figure 15. OBOGS output with "USAFSAM" controller: oxygen concentration vs altitude for product flows (Qp) of 10 and 50 l/min with 33.5-l/min bleed flow.

The controller had a provision for external adjustment of the bleed flow schedule. Making this adjustment simultaneously affected two characteristics of the bleed flow schedule: (1) to increase or decrease the ground-level bleed flow rate, and (2) to change the altitude at which the bleed flow began to decrease. These effects are illustrated in Figures 16 and 17. Both graphs were obtained with an inlet temperature of 80°C and an inlet pressure of 40 psig. Figure 16 represents a product flow set at 10 l/min; and Figure 17, 50 l/min. The traces indicate that a small change in ground-level settings for bleed flow created a more noticeable effect in oxygen concentration at above 8,000-ft cabin altitude.

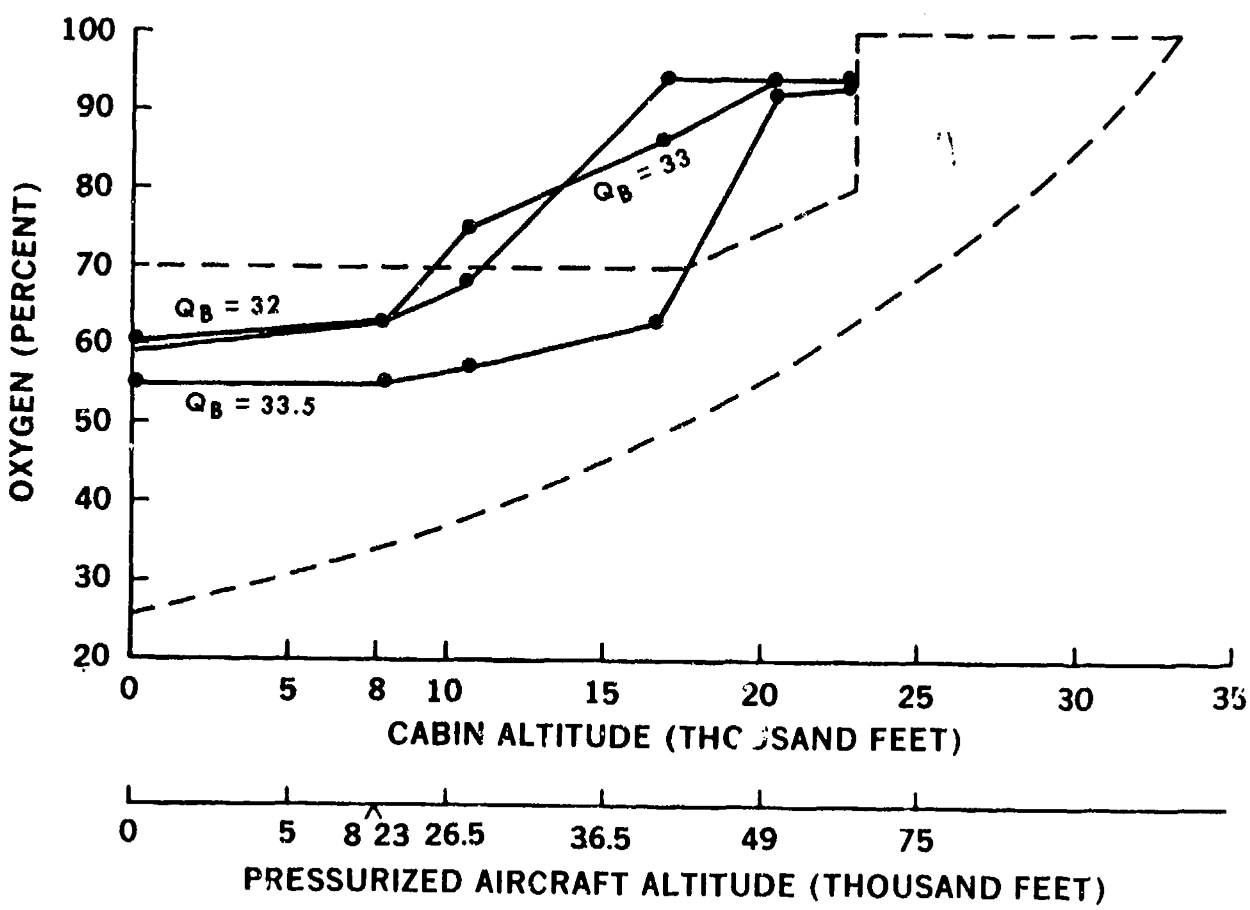

Figure 16. OBOGS output with "USAFSAM" controller: oxygen concentration vs altitude, with 10-l/min product flow and bleed flows (Qb) of 32, 33, and 33.5 l/min.

During laboratory testing, the controller was set to obtain optimum performance; i.e., bleed flow was set to keep the oxygen concentration within the band over the widest range in altitude and demand flow. Figure 17 indicates that with a product flow of 50 l/min, a bleed flow setting of 34.0 l/ min (ground level) caused the backup to activate at approximately 16,000 feet. Figure 16 indicates that with a product flow of 10 l/min, the optimum performance was obtained with the bleed flow set at 33.5 l/min which produced results as shown in Figure 15.

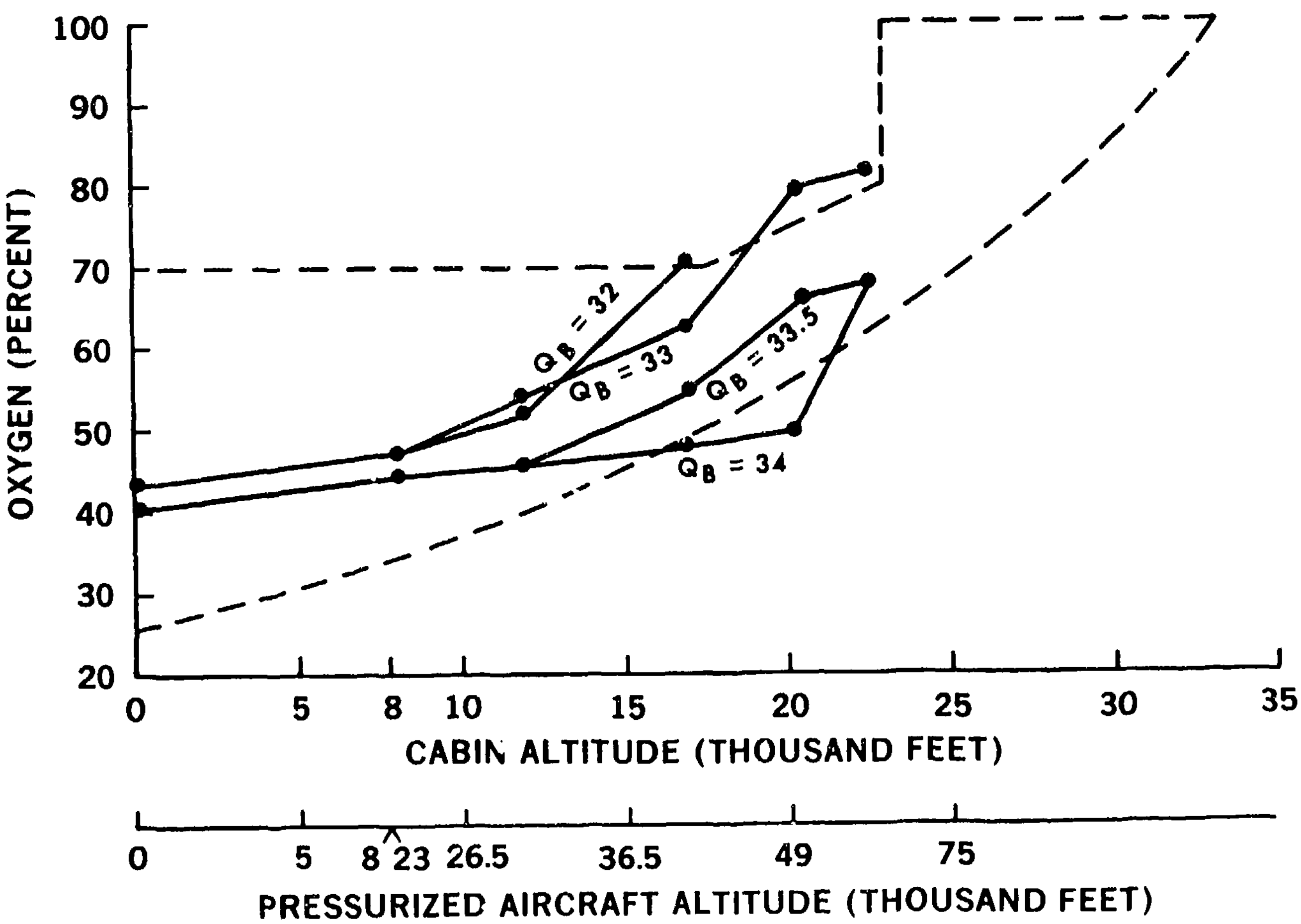

Figure 17. OBOGS output with "USAFSAM" controller: oxygen concentration vs altitude, with 50-l/min product flow and bleed flows (Qb) of 32, 33, 33.5, and 34 l/min.

The USAFSAM controller was set as shown in Figure 15; the aircraft controller, as in Figure 18; and the spare, as in Figure 19. The same procedure was used to obtain the optimum schedule for each controller. The worst-case condition was 40 psig and 80°C; this was the minimum pressure and maximum temperature expected in the F-16. With these settings, the product flow was set for 50 l/min and the bleed flow was adjusted to keep the PO_2 above 195 mmHg, thus keeping the BOS off during normal operations. The three controllers had slightly different characteristic curves for product flows of 10 and 50 l/min. This difference is believed to be caused by slight variations in the springs of the three different controller diaphragms.

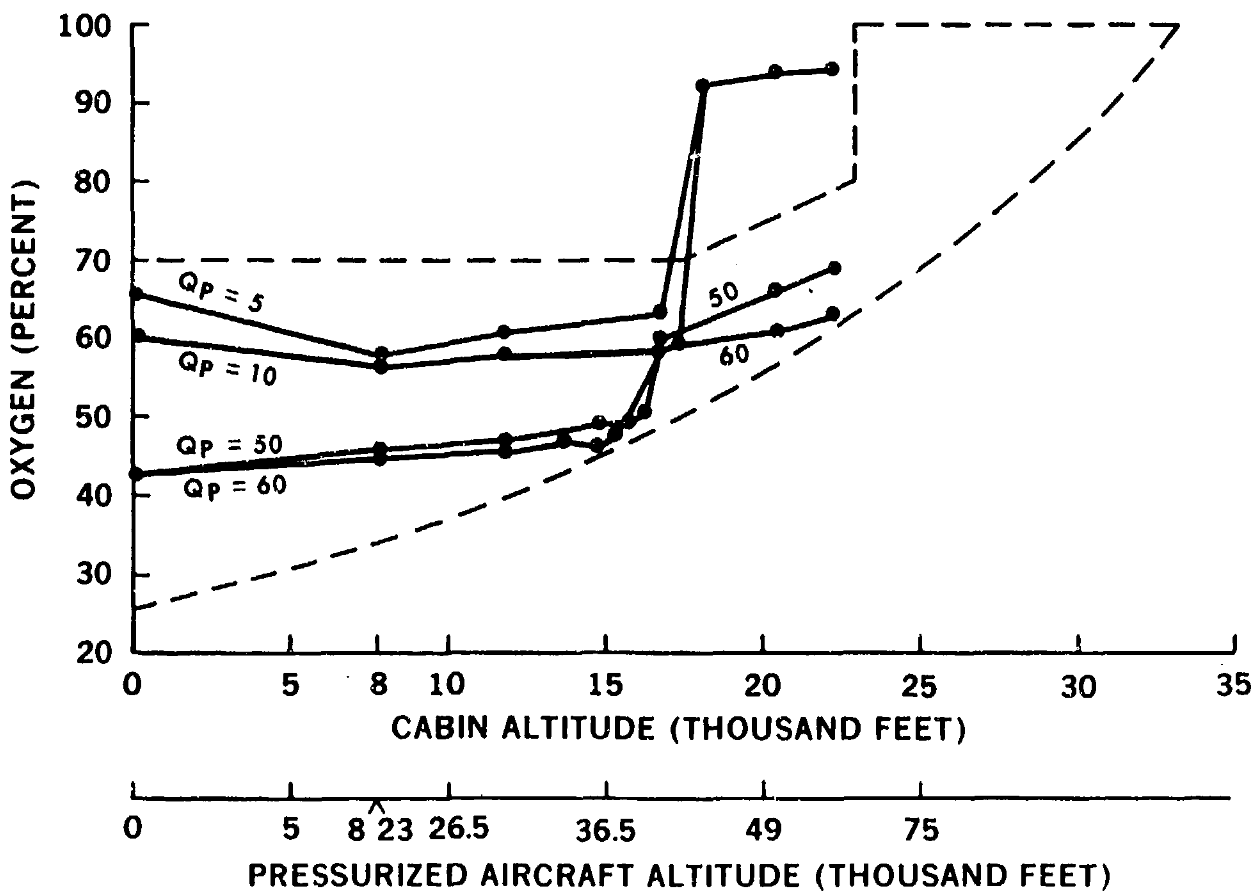

Figure 18. OBOGS output with "aircraft" controller: oxygen concentration vs altitude, with 27-l/min bleed flow and product flows (Qp) of 5, 10, 50, and 60 l/min.

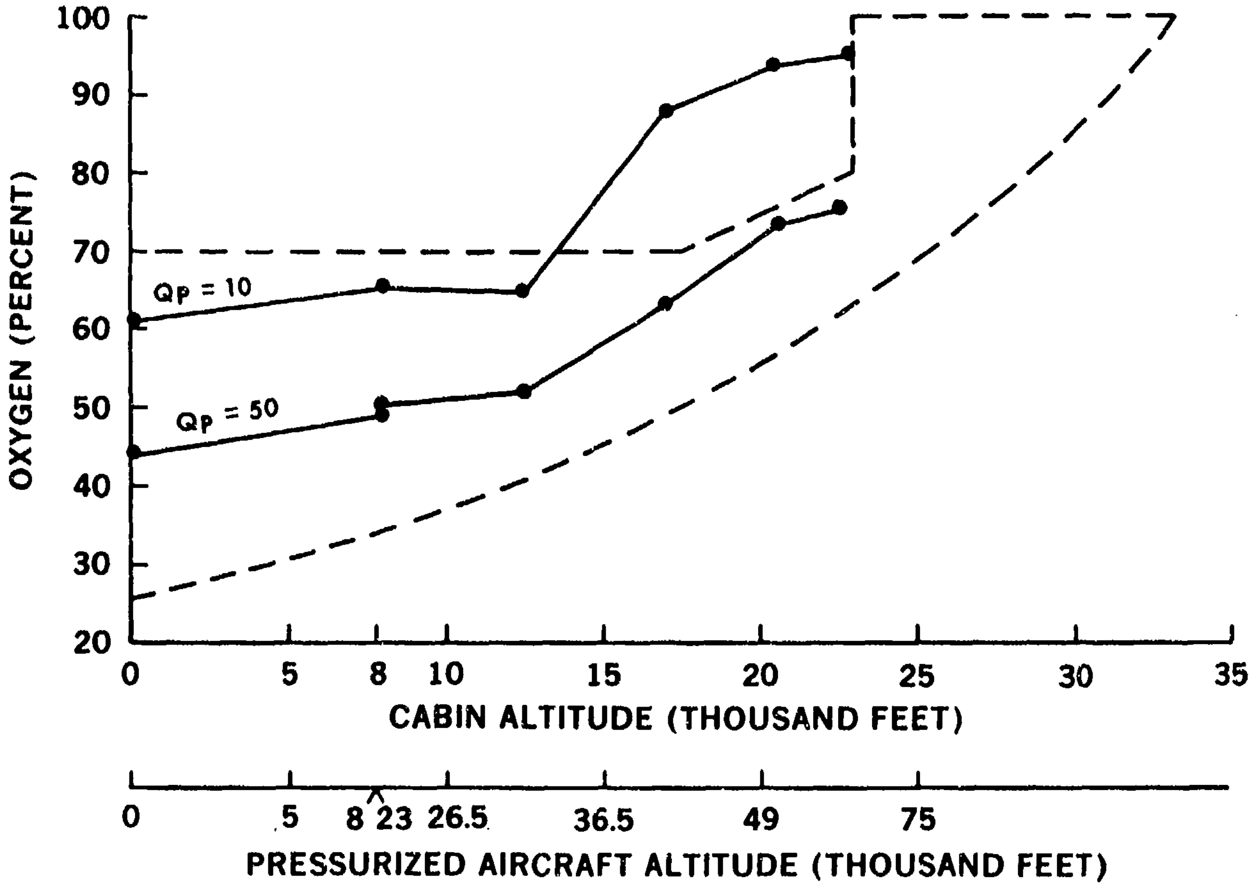

Figure 19. OBOGS output with "spare aircraft" controller: oxygen concentration vs altitude, with 27-l/min bleed flow and product flows (Qp) of 10 and 50 l/min.

At the time the controllers were set, the inlet air temperature to the OBOGS on the aircraft was not well defined. It was believed that the maximum temperature would not exceed 80°C; however, normal operating temperatures would likely be less than 80°C. Figures 20 and 21 show the effect that inlet air temperature had on oxygen concentration for steady product-gas flows of 10 and 50 l/min, respectively, using the USAFSAM controller. Figure 21 indicates that the BOS would be activated if inlet temperature was elevated above 90°C with 50 l/min product flow. However, the flight test program was not expected to encounter 50 l/min sustained product flows or high inlet-air temperatures at the high altitudes where the PO_2 could fall below 195 mmHg.

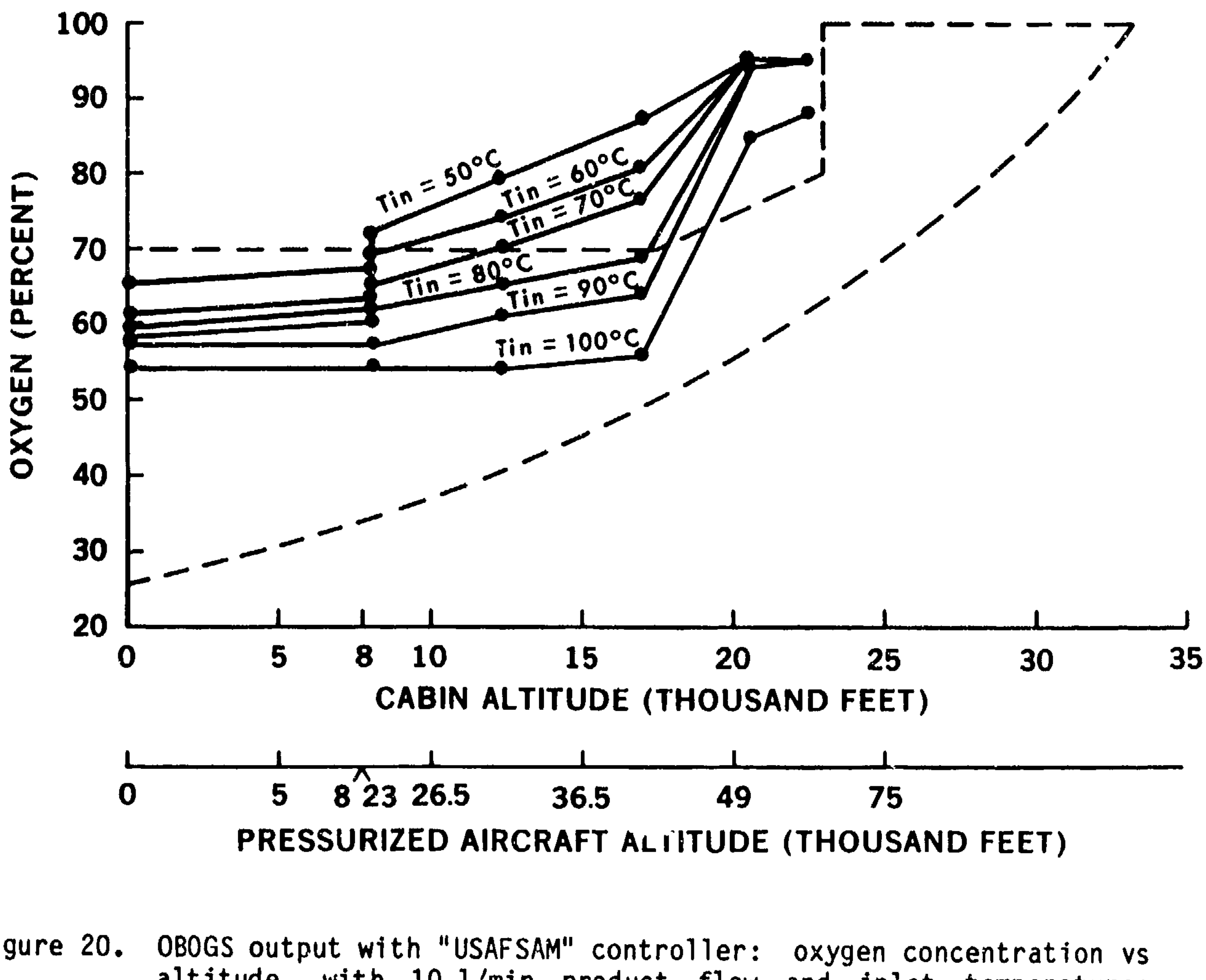

Figure 20. OBOGS output with "USAFSAM" controller: oxygen concentration vs altitude, with 10-l/min product flow and inlet temperatures (Tin) from 50 to 100°C.

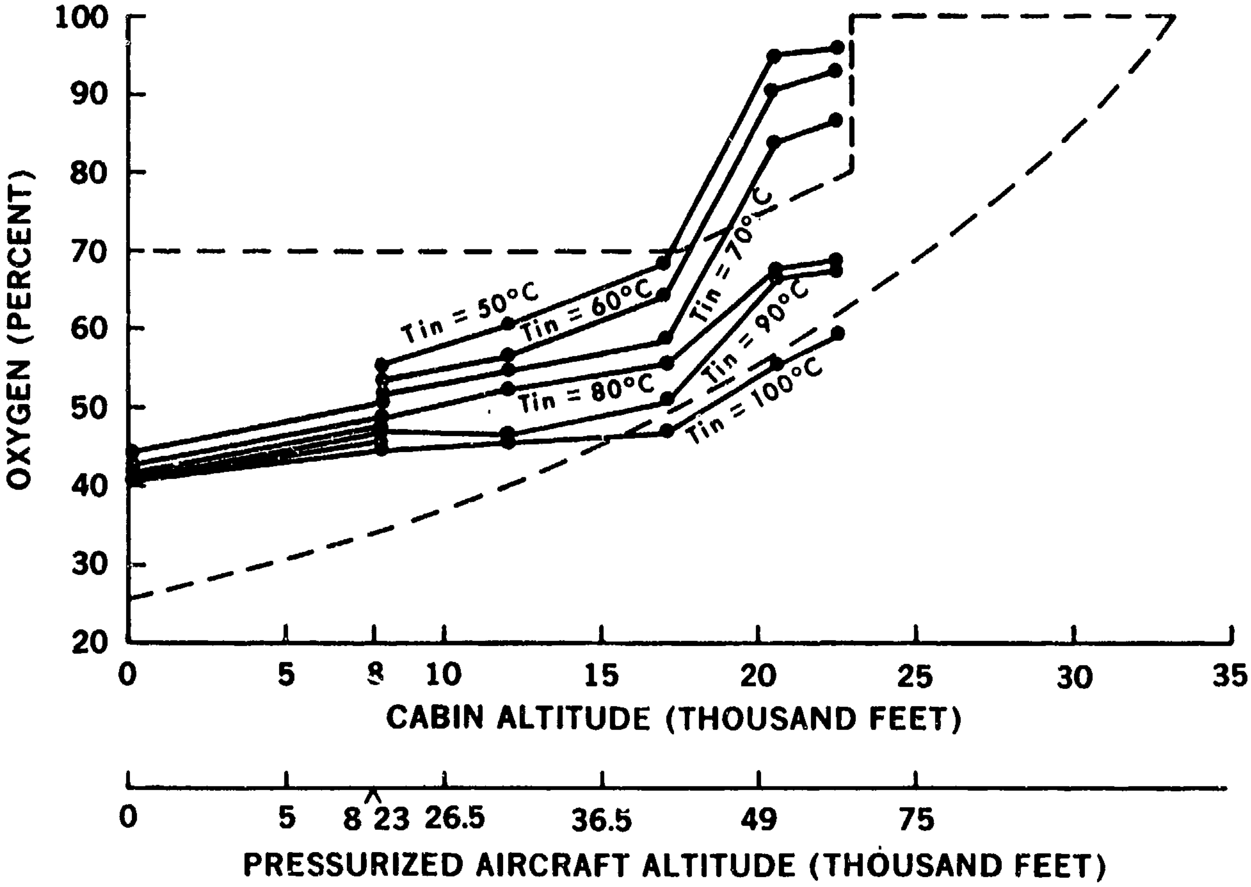

Figure 21. OBOGS output with "USAFSAM" controller: oxygen concentration vs altitude, with 50-l/min product flow and inlet temperatures (Tin) from 50 to 100°C.

Monitor

The OBOGS oxygen monitor output was compared in the laboratory with that of a Perkin-Elmer respiratory mass spectrometer and found to be linear. The monitor output voltage was externally adjustable from the front cover of the regulator/monitor package. Removing the front cover exposed electrical terminals that let the monitor output voltage be read and allowed air to enter the monitor cavity. A potentiometer was adjusted so that the monitor output voltage read the desired voltage as calculated by the formula

$$\text{Desired monitor output voltage} = (A \times B)/29.92$$

where A = the local barometric setting in inHg, and B = percent of oxygen in gas entering the monitor cavity (21% for air).

Regulator

The F-16A OBOGS regulator is a low inlet pressure, nondiluting, pressure-demand regulator that delivers approximately 1-in-wg positive static safety pressure at all altitudes from ground level to 38,000-ft cabin altitude, where pressure breathing begins. The regulator was designed to reduce resistance to breathing and to provide pressure breathing for altitude protection up to 50,000 feet. Regulator evaluation consisted of both static and dynamic testing.

Figure 22 depicts mask-cavity pressure observed for various product flows under steady flow conditions (all tests were performed with a P/Q mask unless otherwise stated). The regulator delivered up to 50 l/min static flow and maintained 1-in-wg safety pressure with inlet pressures as low as 20 psig. Above 50 l/min steady product flow, higher inlet pressures improved regulator performance. A continuous flow of 200 l/min was obtained with inlet pressures above 30 psig.

A breathing machine that produced a sinusoidal breathing pattern was used to test dynamic regulator performance. Figure 23 indicates the maximum and minimum mask-cavity pressures observed when peak inspiratory/expiratory flow was varied from 30 to 200 l/min. Regulator performance was a function of inlet pressure (set at 40 psig in Fig. 23), outlet peak flow, and rate of change in outlet flow. The breathing machine's tidal volume and frequency were first set to obtain a breathing pattern of 30 l/min peak inspiratory flow (Q peak), with a maximum rate of change in inspiratory flow (Q dot max) of 3 l/sec^2. Different settings were then used to obtain peak flows, and corresponding maximum rate of change in flows, of 110 l/min, 11 l/sec^2; 150 l/min, 15 l/sec^2: and 200 l/min, 20 l/sec^2. Thus, Q dot max (in l/sec^2) equals Q peak/10 (in l/min). Mask-cavity pressure swing, shown in Figure 24, was the difference between maximum inspiratory and expiratory mask-cavity pressure.

As cabin altitude increased to approximately 20,000 feet, resistance to breathing decreased as indicated in Figures 25 and 26. Figure 25 displays the mask-cavity minimum- and maximum-pressure curves with a breathing demand (minute volume) of 30 l/min peak flow and a Q dot max of 3 l/sec^2. With breathing demand at 200 l/min (Fig. 26), resistance to breathing was greater than with demand at 30 l/min.

As cabin altitude went above 38,000 feet, the regulator pressure breathing schedule increased the mask-cavity pressure. Figure 27 shows this relationship with a steady flow of 50 l/min. Figure 28 data, obtained with dynamic breathing peak flow of 30 l/ min, shows the minimum and maximum mask pressure; the average of these pressures is shown in Figure 29. Figures 30 and 31 are similar to Figures 28 and 29 but with peak flow set at 110 l/min.

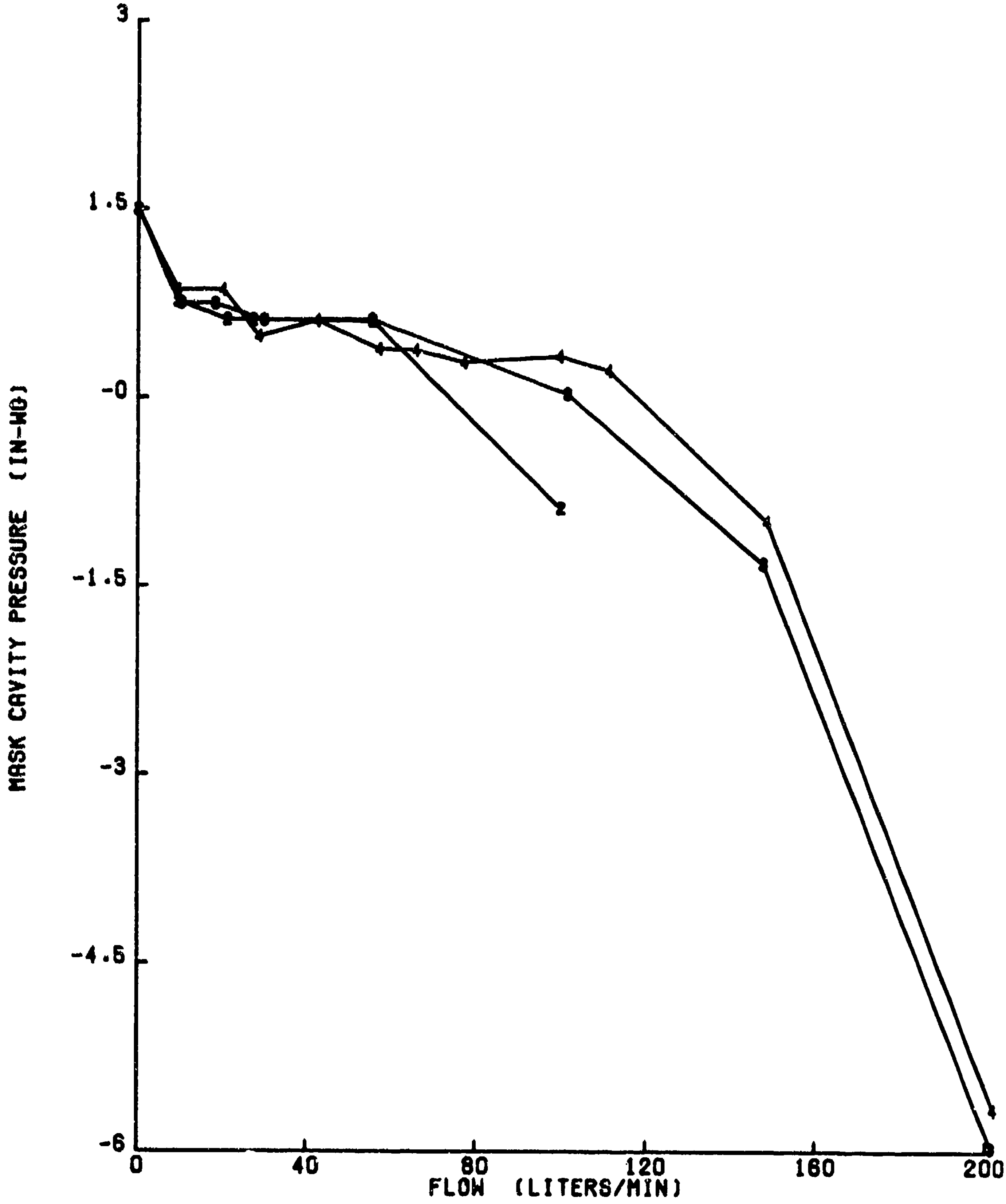

Figure 22. Concentrator, regulator, and P/Q mask: mask-cavity pressure vs steady flow at ground level, with inlet pressures of 20, 30, and 40 psig. (2 = 20, 3 = 30, 4 = 40 psig)

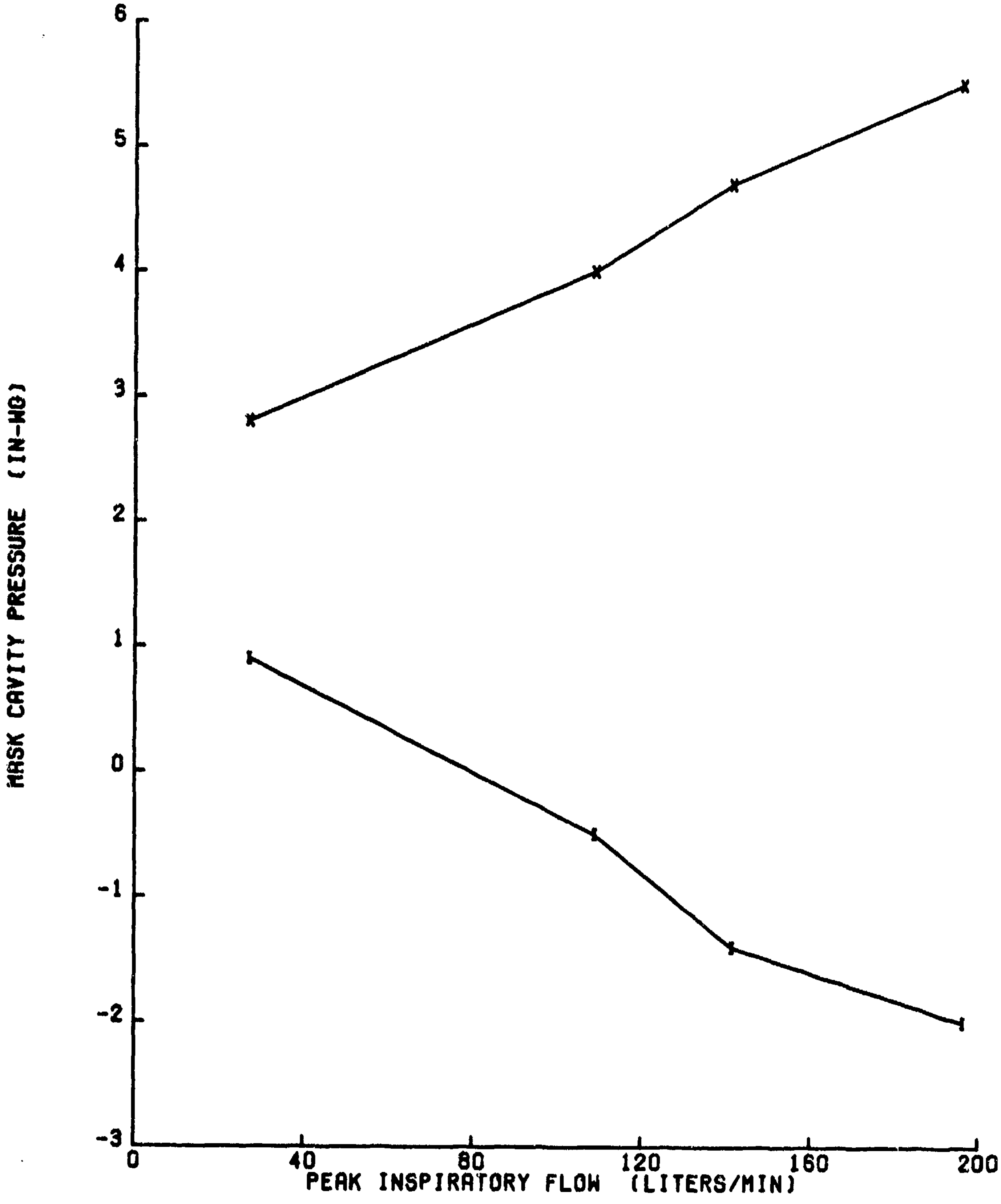

Figure 23. Concentrator, regulator, and P/Q mask: maximum (X) and minimum (I) mask-cavity pressures vs dynamic flow at ground level, with 40-psig inlet pressure. (Maximum rate of change in flow (l/sec^2) equals peak inspiratory flow (l/min) divided by ten: Q dot max = Q peak/10)

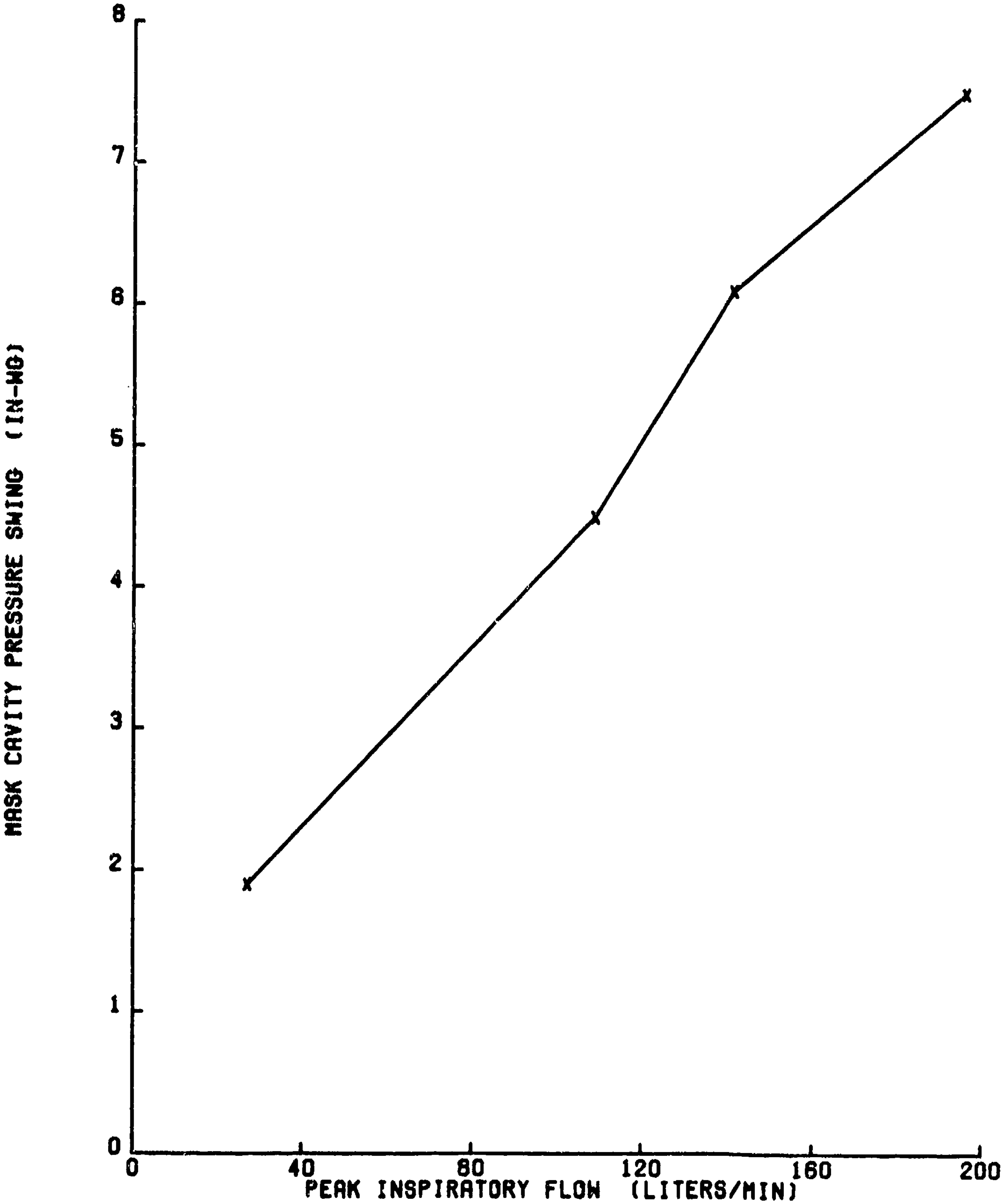

Figure 24. Concentrator, regulator, and P/Q mask: mask-cavity pressure swing vs dynamic flow at ground level, with 40-psig inlet pressure.

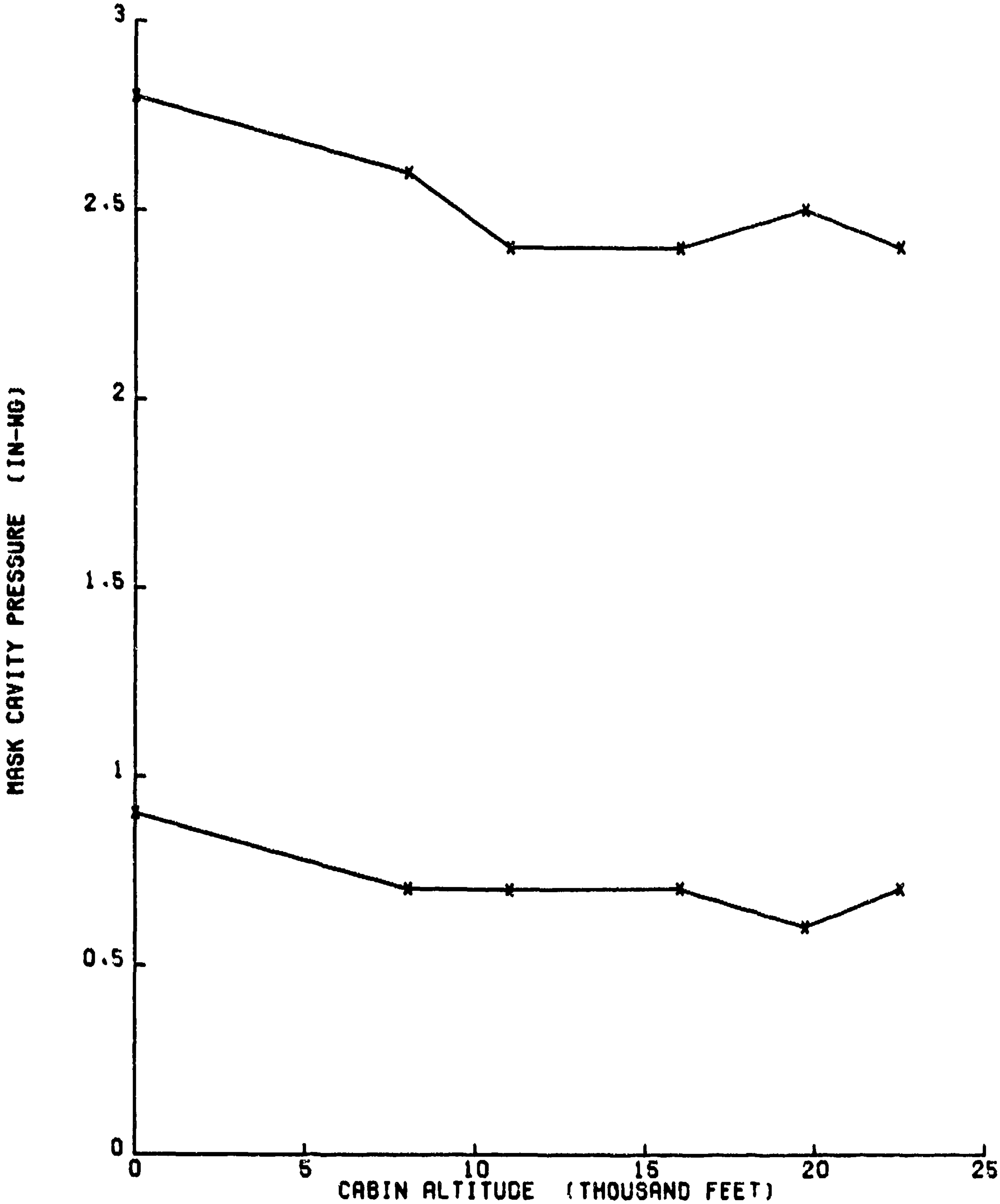

Figure 25. Concentrator, regulator and P/Q mask: mask-cavity pressure vs altitude, with 40-psig inlet pressure, 30-l/min dynamic Q peak, and 3-l/sec^2 Q dot max.

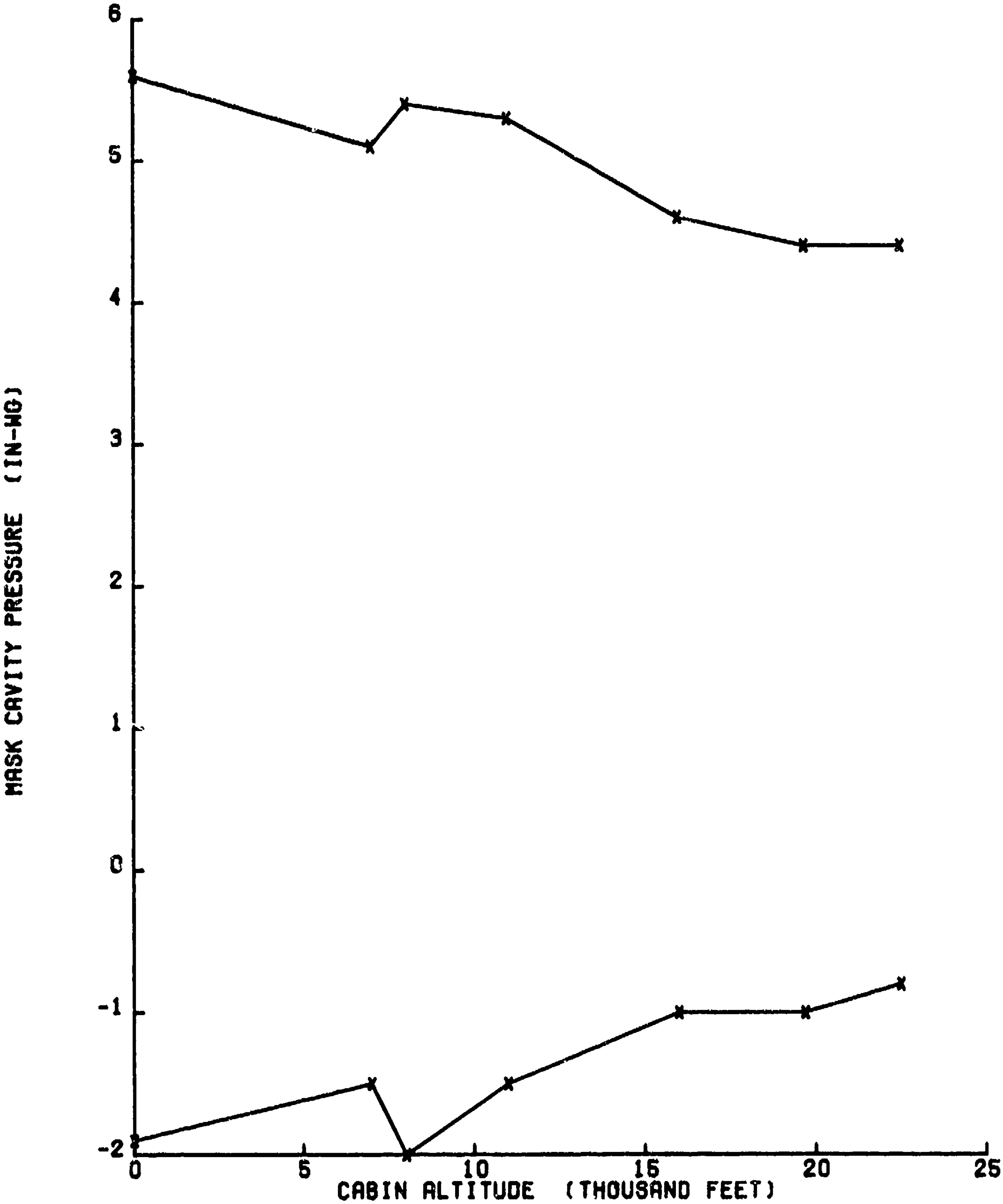

Figure 26. Concentrator, regulator, and P/Q mask: mask-cavity pressure vs altitude, with 40-psig inlet pressure, 200-l/min dynamic Q peak, and 20-l/sec^2 Q dot max.

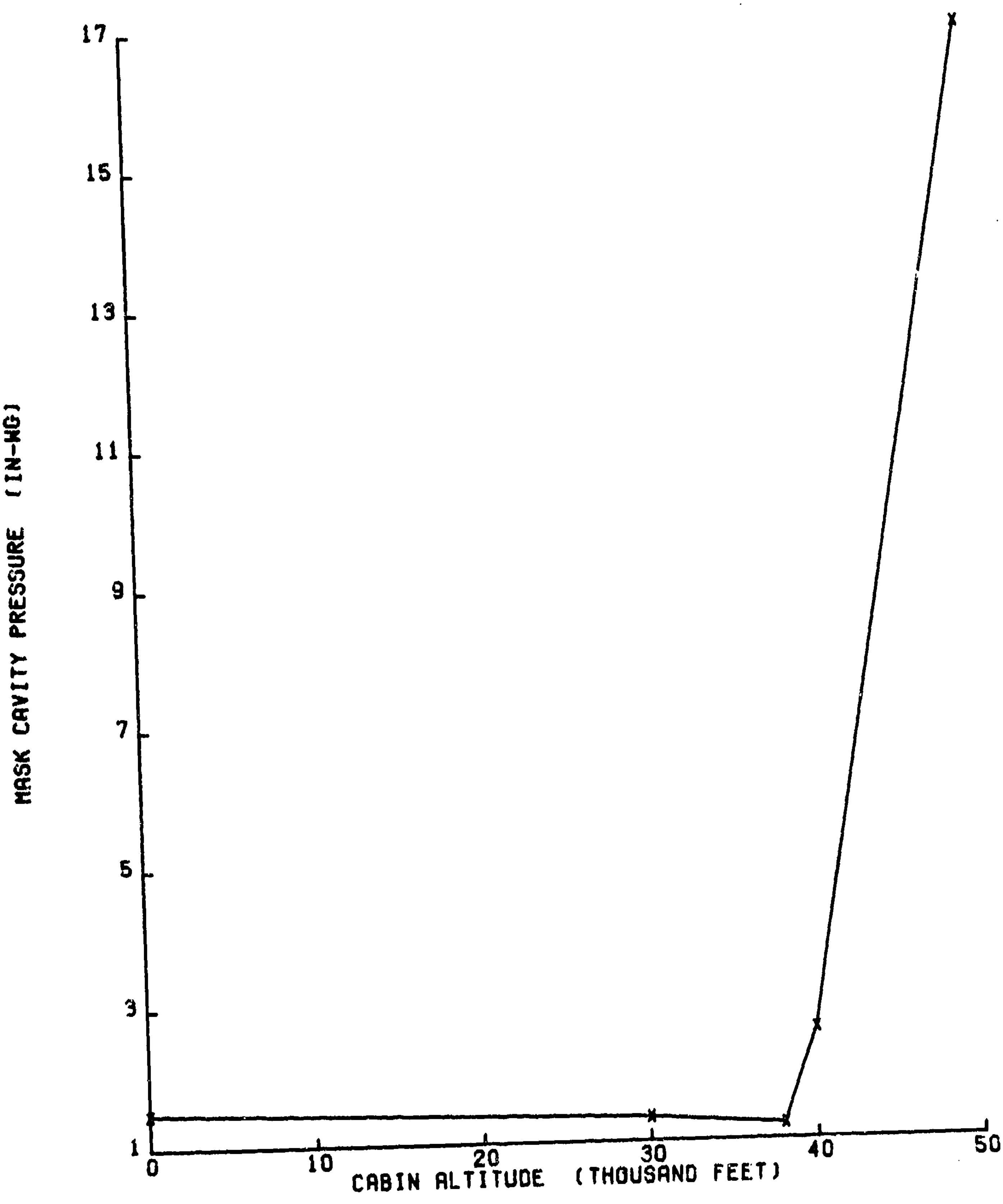

Figure 27. Regulator pressure breathing schedule: mask-cavity pressure vs unpressurized cabin altitude, with 40-psig inlet pressure and 50-l/min steady flow.

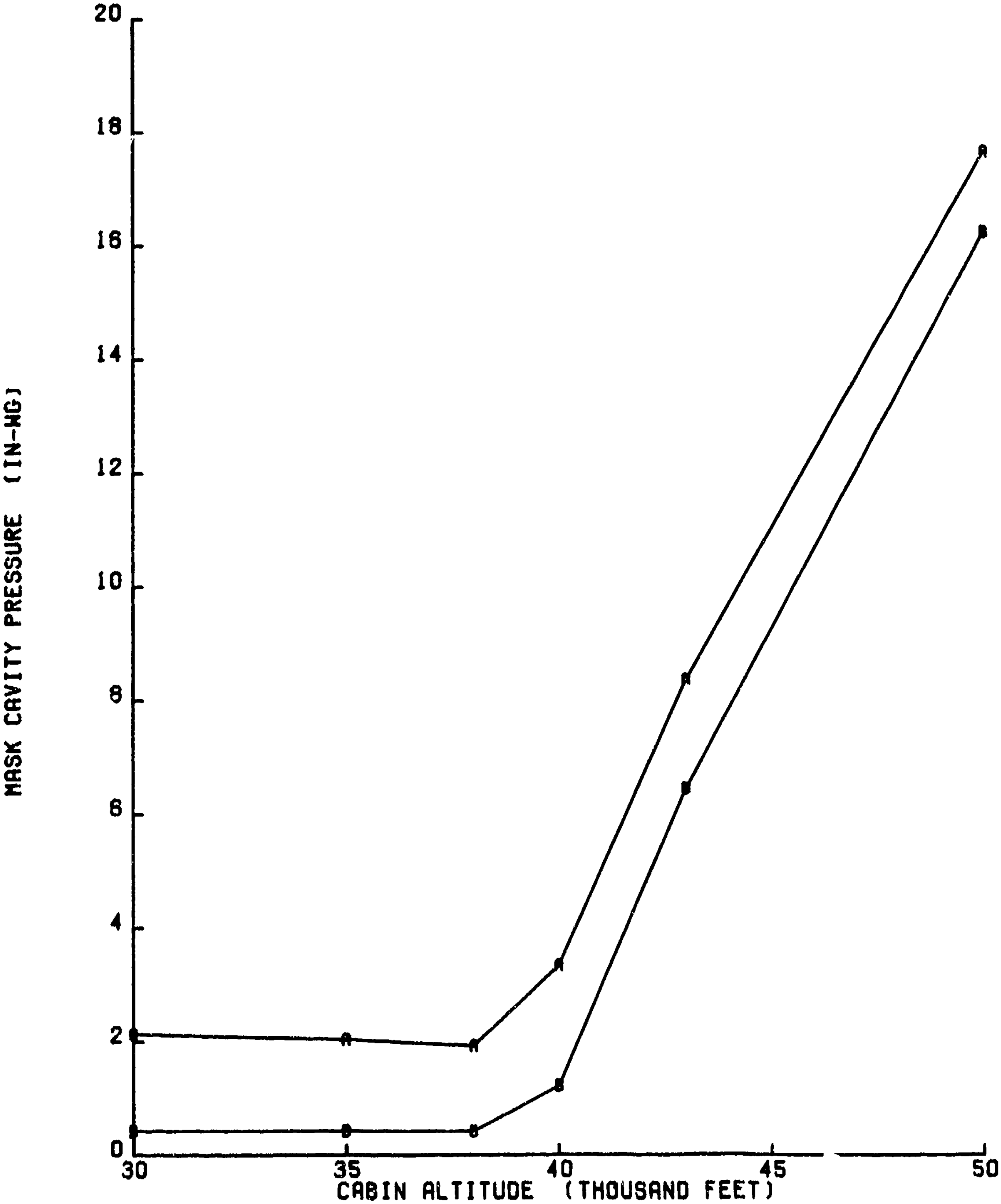

Figure 28. Regulator pressure breathing schedule: mask-cavity pressure vs unpressurized cabin altitude, with 40-psig inlet pressure and 30-l/min dynamic Q peak. (A = maximum, B = minimum pressure)

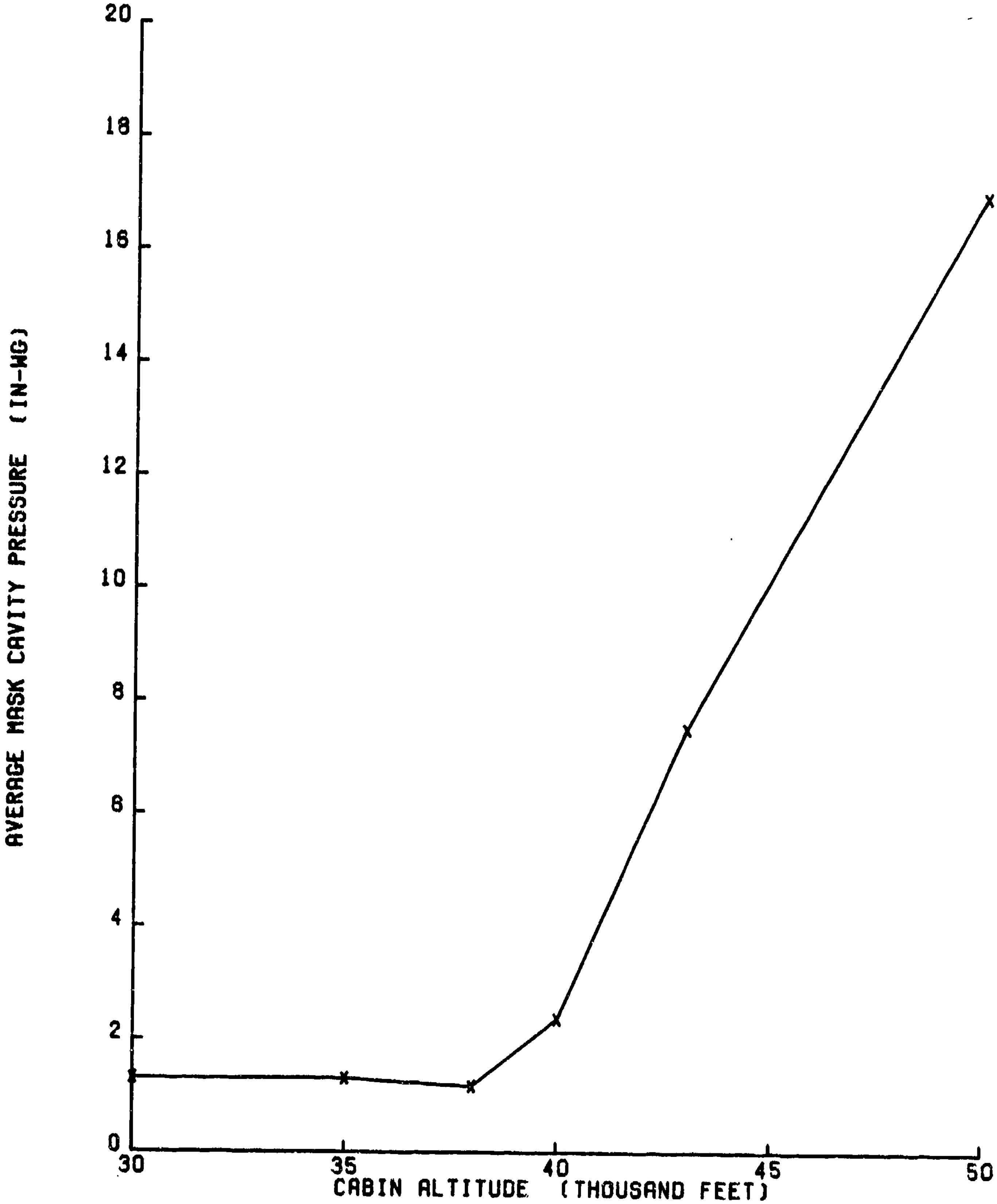

Figure 29. Regulator pressure breathing schedule: average mask-cavity pressure vs unpressurized cabin altitude, with 40-psig inlet pressure and 30-l/min dynamic Q peak.

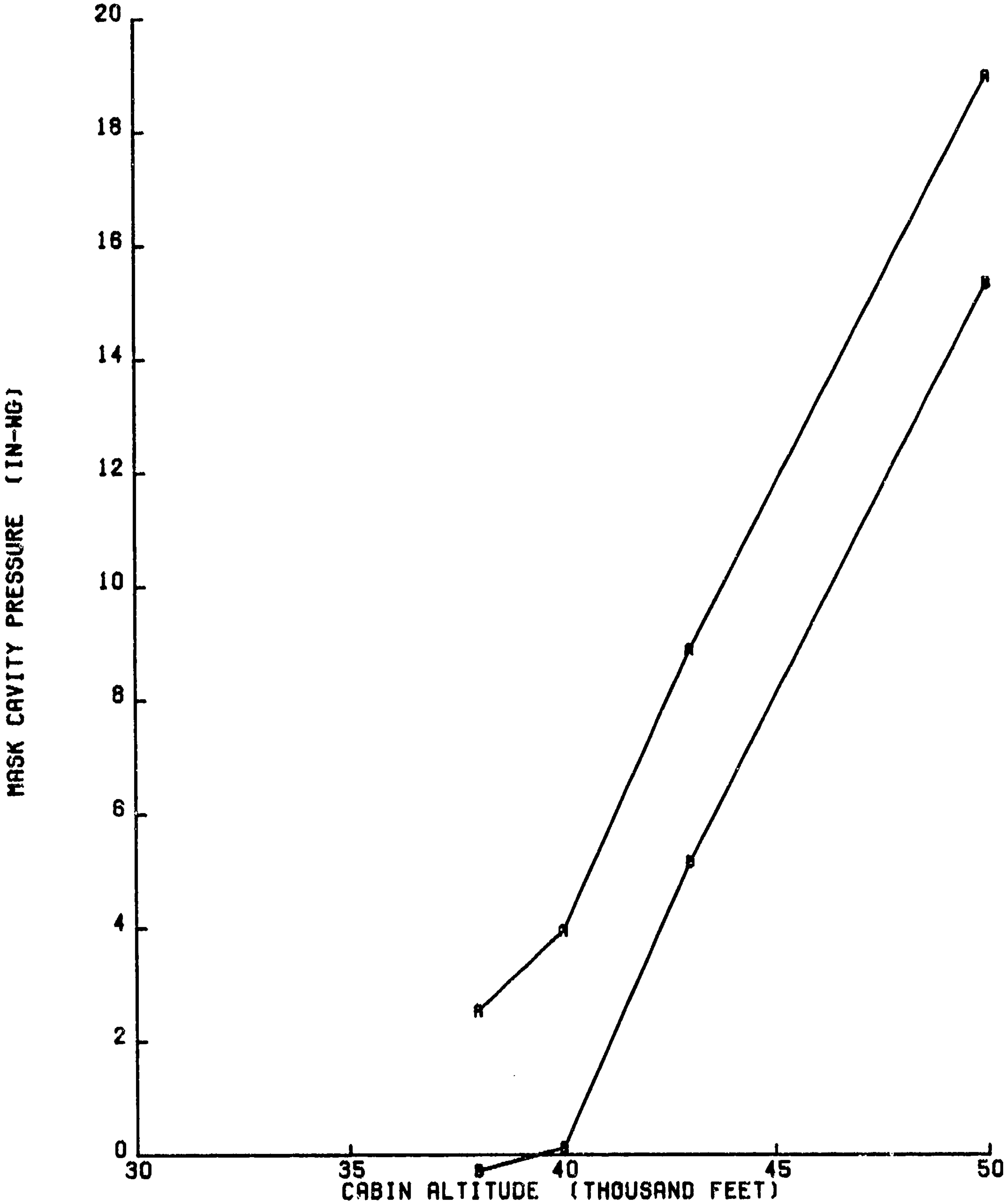

Figure 30. Regulator pressure breathing schedule: mask-cavity pressure vs unpressurized cabin altitude, with 40-psig inlet pressure and 110-l/min dynamic Q peak. (A = maximum, B = minimum pressure)

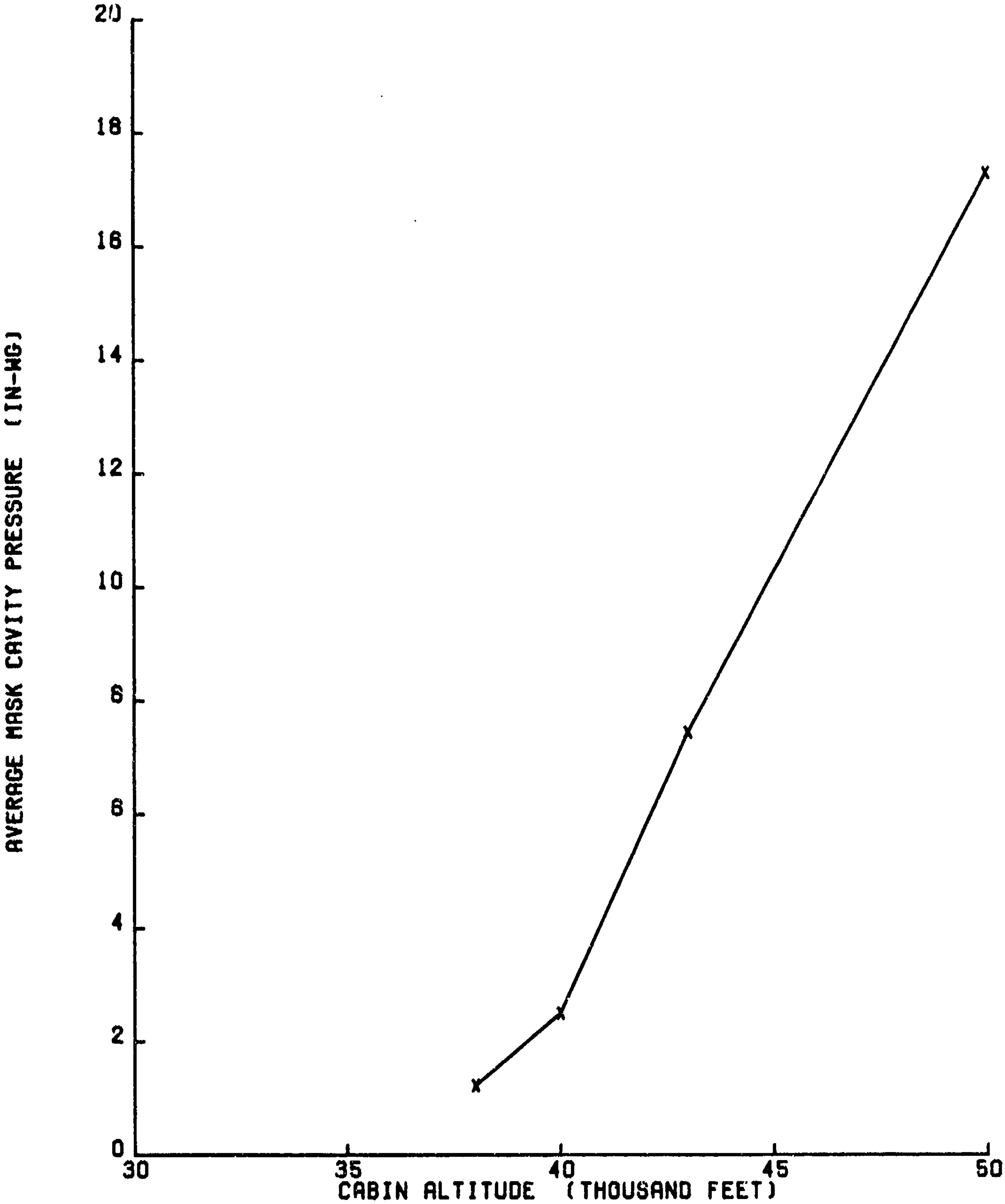

Figure 31. Regulator pressure breathing schedule: average mask-cavity pressure vs unpressurized cabin altitude, with 40-psig inlet pressure and 110-l/min dynamic Q peak.

As the inlet air pressure cycles through the concentrator beds, the OBOGS product pressure simultaneously cycles. Peak pressure at the regulator inlet was approximately 38 psig, while the minimum pressure varied with product gas flow. Prior to OBOGS laboratory testing, there was concern that minimum product pressure, or regulator inlet pressure, might be insufficient to operate the regulator. Also, if regulator inlet pressure dropped below 10 psig, the BOS might be activated. Regulator inlet pressure was a function of (1) OBOGS outlet gas pressure, (2) the length, diameter, and routing of the connecting line between the concentrator and regulator, and (3) product gas flow. Figure 32 shows the regulator outlet (product gas) flow, mask-cavity pressure, and regulator inlet and outlet pressure when the peak concentrator inlet pressure was 40 psig. With peak product flow of approximately 150 l/min, the regulator received sufficient inlet gas pressure (23-38 psig) to operate correctly. A mask-cavity pressure swing from -1.0 to +4.5 in-wg corresponded to a comparable swing in regulator outlet pressure. As the OBOGS concentrator flow alternated from bed to bed, the regulator inlet pressure cycled from 38 to 23 psig due to the intermittent pressurization of the beds. As product gas was delivered to the mask, corresponding reductions occurred in the regulator inlet pressure. When these reductions synchronized with minimum concentrator outlet pressures, the resultant regulator inlet pressure was at a minimum.

The synchronizing effect is also demonstrated in Figure 33, where peak product flow was set at 200 l/min. On every fourth breath, product demand synchronized with minimum concentrator outlet pressure. When this happened, regulator inlet pressure dropped to 15 psig, which was sufficiently low to affect regulator performance. As the regulator attempted to deliver a 200-l/min breath in synchrony with minimum concentrator outlet pressure, the inspiratory mask-cavity pressure (-4 vs -3 in-wg) increased slightly. This occurred because the regulator diaphragm had opened farther than usual to compensate for the reduced regulator inlet pressure. The subsequent expiration therefore required an increase in mask-cavity pressure to overcome the product gas flow and open the expiratory valve. The result was an increase in expiratory resistance from 6 to 19 in-wg, and a reduction in peak flow for these "restricted" breaths to about 185 l/min.

The synchronizing effect between product gas flow and concentrator outlet pressure did not degrade regulator performance with peak product flow up to 150 l/min. Only the highest product flow (200 l/min) produced a noticeable change in mask-cavity pressures. Also, mask-cavity pressure increased only when the peak product flow coincided with minimum concentrator outlet pressure. Our considered opinion is that this will occur infrequently during normal operation; and even if it should occur, the pilot may feel only a harmless, transitory puff of pressure in the mask cavity during expiration and may notice only a very mild restriction of inhalation for a single breath.

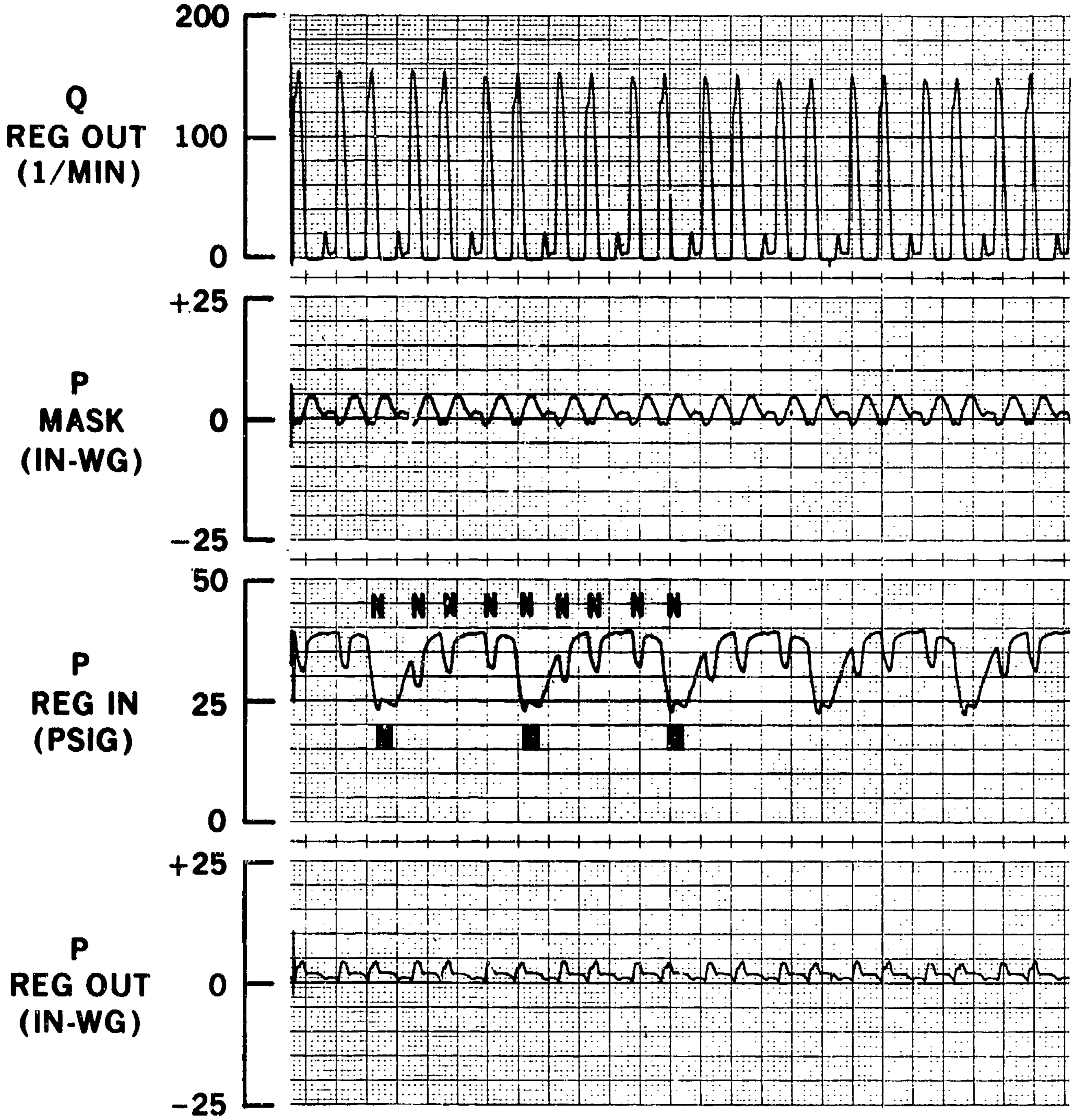

Figure 32. Concentrator, mask, and regulator performance with 40-psig inlet pressure and 150-l/min dynamic peak flow. (m = minimum inlet pressure; n = reduction in inlet pressure)

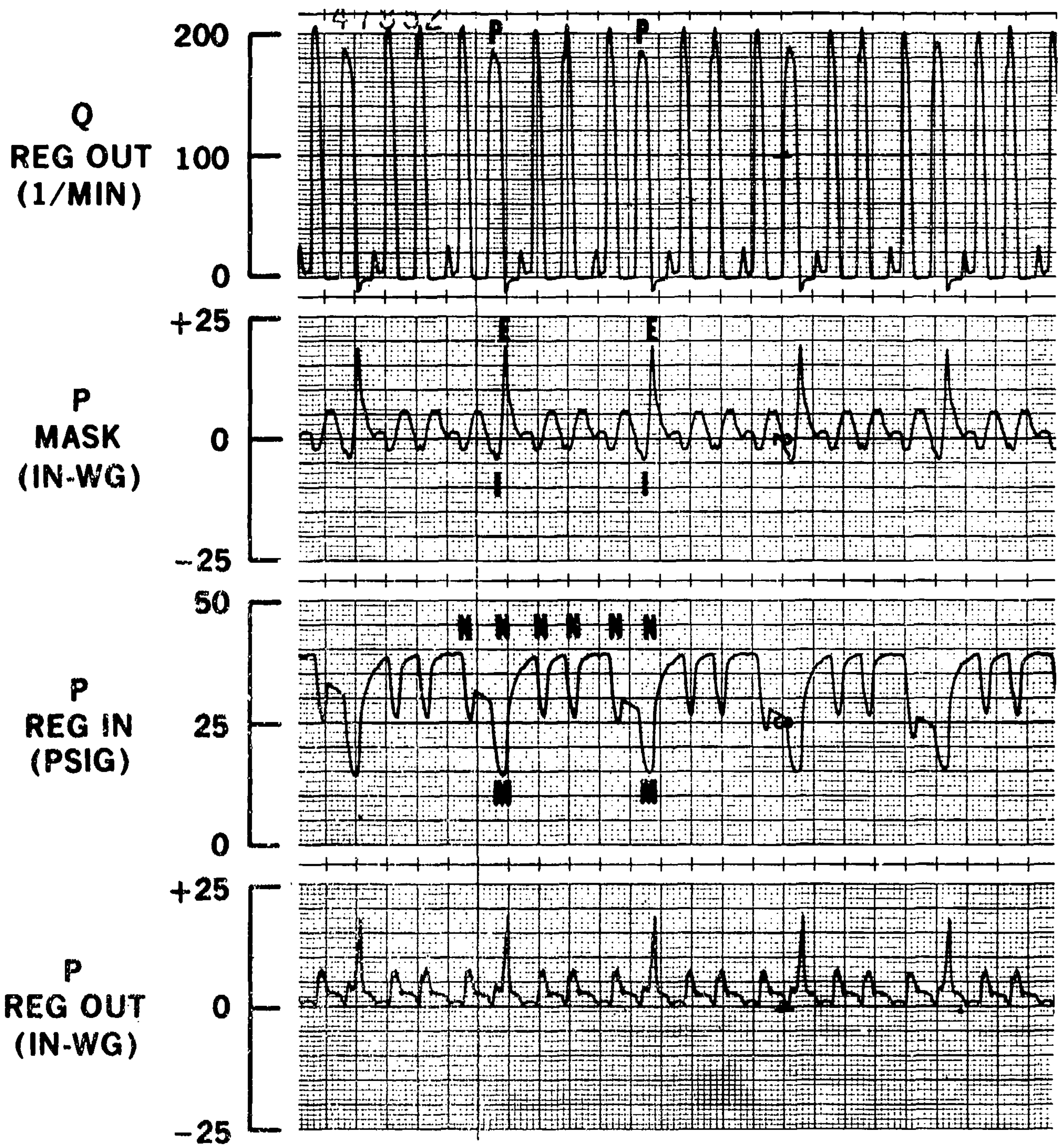

Figure 33. Concentrator, regulator, and mask performance with 200-1/min dynamic peak flow. (E = peak expiratory pressure; I = inspiratory pressure; m = minimum inlet pressure; n = reduction in inlet pressure; p = reduction in peak flow)

Mask

Three masks--the United Kingdom P/Q and the USAF MBU-5/P and MBU-12/P--were tested with the other OBOGS components. Dynamic tests included flow rates from 20 to 200 l/min as indicated in Figure 34. Each mask gave similar pressure-swing characteristics at the 20-l/min flow rate. However, as peak flow increased, the P/Q mask exhibited a much lower resistance to breathing. Up to 100 l/min, the expiratory mask-cavity pressure was similar for all masks; however, the inspiratory pressure was much less in the P/Q mask. At higher flow rates (such as those experienced during speech or M-1 maneuvers), the P/Q mask gave a much lower pressure swing than did the MBU-5/P or 12/P mask.

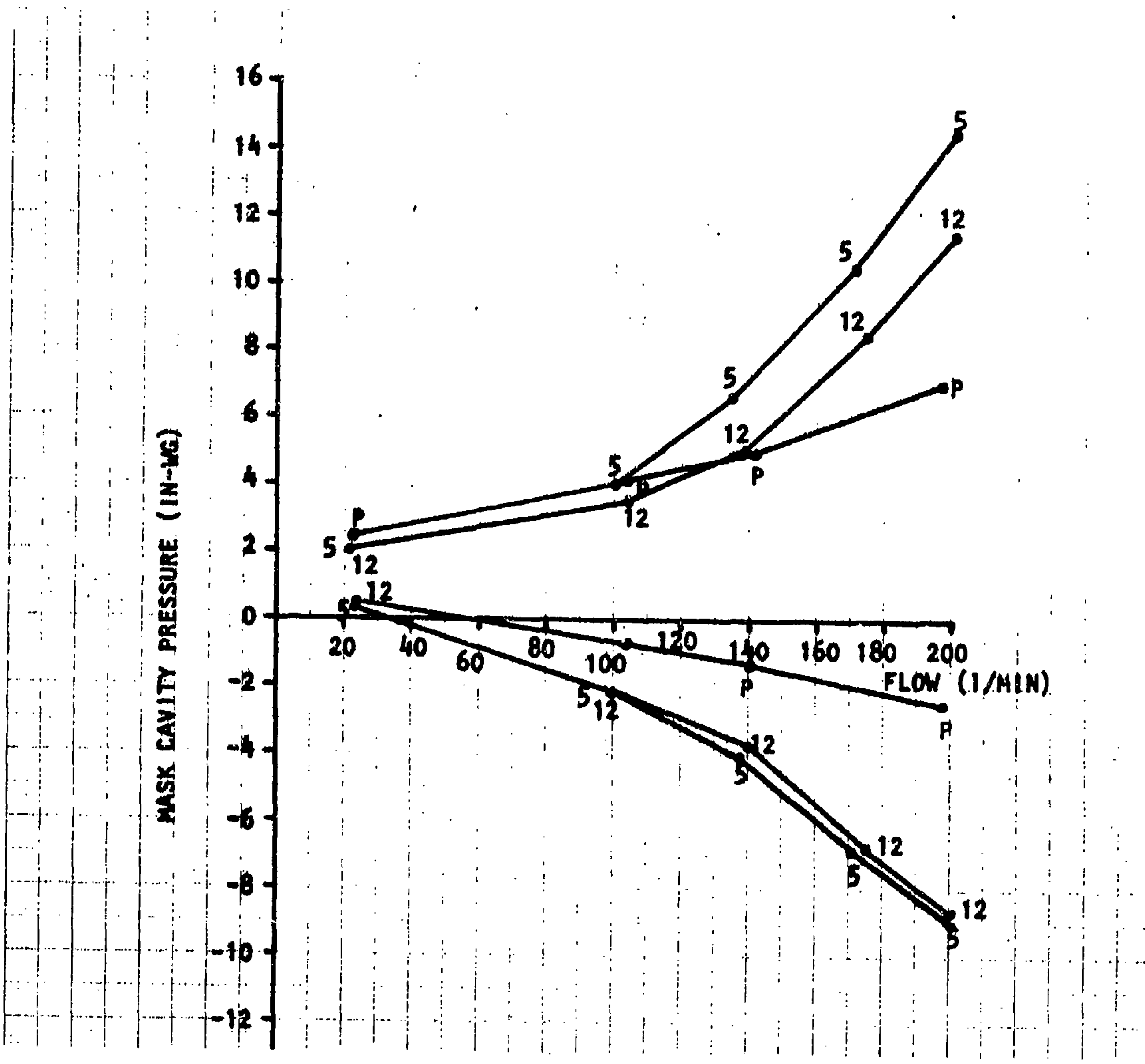

Figure 34. Comparison of the P/Q mask with the MBU-12/P and MBU-5/P masks.

Selector Valve/BOS

The OBOGS selector valve was tested to verify proper operation during manual and automatic switching between OBOG and BOS. During this test, the oxygen-low and selector-valve lights were monitored and the mask-cavity pressure and product gas composition were recorded while various malfunctions were simulated. Results of this test are shown in Table 1. Manual and automatic switching of the selector valve functioned as specified under all conditions. Caution-light symbology, however, was not completely straightforward. When the selector valve was in the backup position, the SV yellow caution light stayed lit after the backup bottle was depleted (case 4C, Table 1). Also, when the selector valve was in the OBOG position, the SV caution light did not illuminate when the system pressure was below 10 psig even though the BOS was supplying the breathing gas (case 2C). The selector valve regulated BOS pressure from 1800 to 60 psig in accordance with the OBOGS specification. Therefore, whenever the BOS was selected, mask-cavity pressure was not affected.

TABLE 1. F-16A ONBOARD OXYGEN GENERATING SYSTEM SWITCHOLOGY

Selector valve	Lights		Gas source	Condition/Malfunction
	OXY	SV		
1 A OFF	-	-	OBOG	Normal; Bottle empty; DC off
B	ON	ON	OBOG	Low PO_2; Low pressure; Press-to-Test
2 A OBOG	-	-	OBOG	Cabin alt < 31K; Bottle empty; DC off
B	-	ON	BOS	Cabin alt > 31K
C	ON	-	BOS	Low pressure
D	ON	-	OBOG	Low PO_2
3 A AUTO	-	-	OBOG	Cabin alt < 25K; Bottle empty; DC off
B	-	ON	BOS	Cabin alt > 25K
C	ON	ON	BOS	Low PO_2; Low pressure
4 A BU	-	ON	BOS	Normal
B	ON	ON	BOS	Low PO_2; Low pressure
C	-	ON	OBOG	O_2 bottle empty
D	-	-	BOS	DC off

Rapid Decompression Testing

Rapid decompression testing was conducted with the concentrator maintained at aircraft altitude and the cockpit-mounted components at cabin altitude. A variable orifice valve located between the cabin-altitude chamber and a large accumulator opened quickly to allow rapid decompression. Decompression time was controlled by adjusting the orifice size between the two chambers. The decompression time (delta t) was measured from when the cabin altitude started to rise until 90% of the final aircraft altitude was reached. Decompression testing was conducted with a breathing machine, brass mannequin head, and a P/Q mask, together with the cockpit-mounted components. During the decompression, peak mask-cavity pressure was recorded and plotted against 1/delta t (Fig. 35). During unmanned testing, rather large peak mask pressures occurred due to the experimental setup. A leakproof putty compound sealed the mask to the mannequin head, thus preventing the expanding gas from venting around the mask seal. Also, the breathing machine and associated plumbing did not adequately represent the human respiratory capacity and compliance characteristics. Nonetheless, this type of experimental setup was useful to verify proper operation of the regulator during rapid decompressions. With a leakproof oronasal mask seal, expanding gases in the regulator and mask supply hoses were forced to escape backward through the regulator relief port, reducing the regulator outlet pressure until the compensated mask expiratory valve could open and vent expanding gas in the lungs and mask cavity. Figure 35 illustrates the linear relationship between duration of decompression and peak mask-cavity pressure. This relationship did not depend on initial and final altitude because all decompressions represented a 5 psi differential between the cabin and aircraft pressures.

Acceleration Testing

The entire OBOGS was mounted in the USAFSAM centrifuge and tested with g loads up to +10 G_z, using both steady and dynamic product flows. The concentrator, selector valve, and regulator package were independently oriented with respect to the G_z vector while system parameters were recorded. The only component that demonstrated any G_z effect was the P/Q mask which tended to leak around the expiratory valve under high-G_z loads. This effect was strictly a mask phenomenon and did not degrade OBOGS performance. No other adverse effects were noted during acceleration testing.

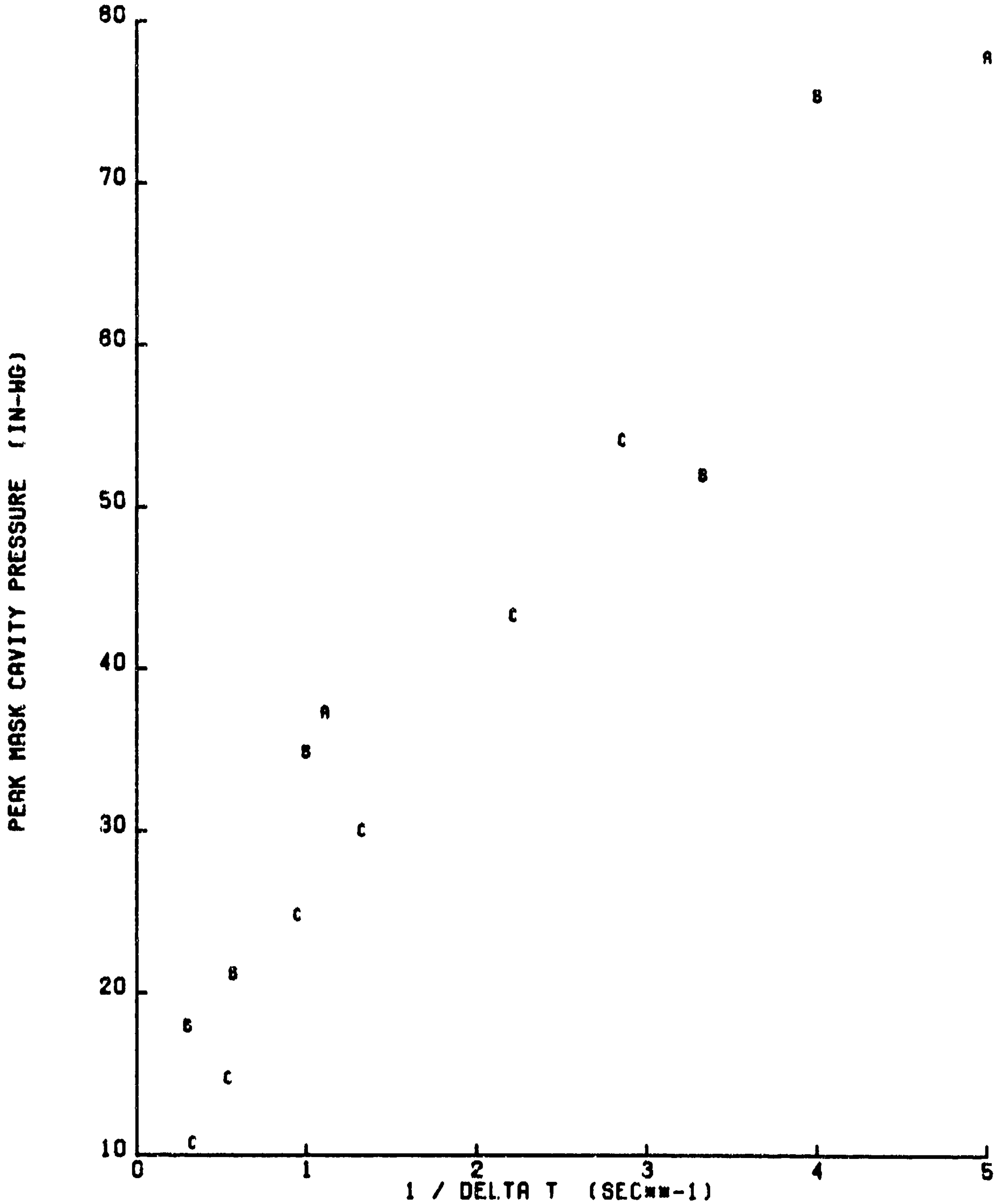

Figure 35. Unmanned rapid decompression testing: peak mask-cavity pressure vs decompression time (1/delta t), with 40-psig inlet pressure. (initial/final altitudes (K ft): A = 12/30, B = 16.8/40, C = 8/20)

MAN RATING

OBOGS man rating consisted of having human subjects breathe from the system during altitude-chamber flights, rapid decompression testing, and acceleration testing.

Altitude Testing

Five subjects were used for OBOGS altitude tests. The altitude profile included breathing at ground level, first while the subjects were at rest and then while talking. The subjects also exercised at light and medium work loads on a bicycle ergometer, in silence and then with speech. The rest/exercise/speech protocol was repeated at 8,000-ft altitude. Normal breathing with speech was repeated at 22,000 feet and at 40,000 feet. Cabin altitude was then reduced to 10,000 feet, where M-1 maneuvers were performed.

During these tests, mask-cavity pressure and product gas composition and flow were recorded in addition to several other system and physiological parameters. The concentrator was supplied with 80°C inlet air at 40 psig. Product gas composition stayed within the specified bounds (Fig. 36), and the system automatically switched to BOS as cabin altitude exceeded 25,000 feet. Between 25,000 and 31,000 feet, the subjects could manually select OBOGS product gas via the selector valve; above 31,000 feet, BOS gas was automatically delivered to the subjects.

Figure 37 is a scatter diagram that indicates mask-cavity pressure as a function of peak inspiratory flow and altitude. As expected, mask-cavity pressures increased with increasing product flows. The variation in mask pressure at any one product flow was due to the different breathing patterns and rates of change in flow for different subjects, which resulted from different types of activities; i.e., rest, exercise, speech, and M-1 maneuvers. Variation in mask pressure was also due, in part, to the synchronizing effect between the concentrator and product-demand flow.

Rapid Decompression Testing

Four subjects were used for rapid decompression testing. The subjects were placed in a decompressible altitude chamber with the OBOGS regulator, selector valve, and BOS. The concentrator was placed in an altitude chamber that was maintained at aircraft altitude. Two subjects underwent rapid decompressions from 8,000 to 23,000 feet, and two from 16,800 to 40,000 feet. These results are plotted in Figure 38. A comparison of manned-vs-unmanned rapid decompressions revealed that mask-cavity pressures for decompressions of similar duration were much lower in the manned decompressions and were well within the desired mask-cavity limits. Because of human-safety considerations, the manned decompressions were of much less duration than many of the unmanned decompressions.

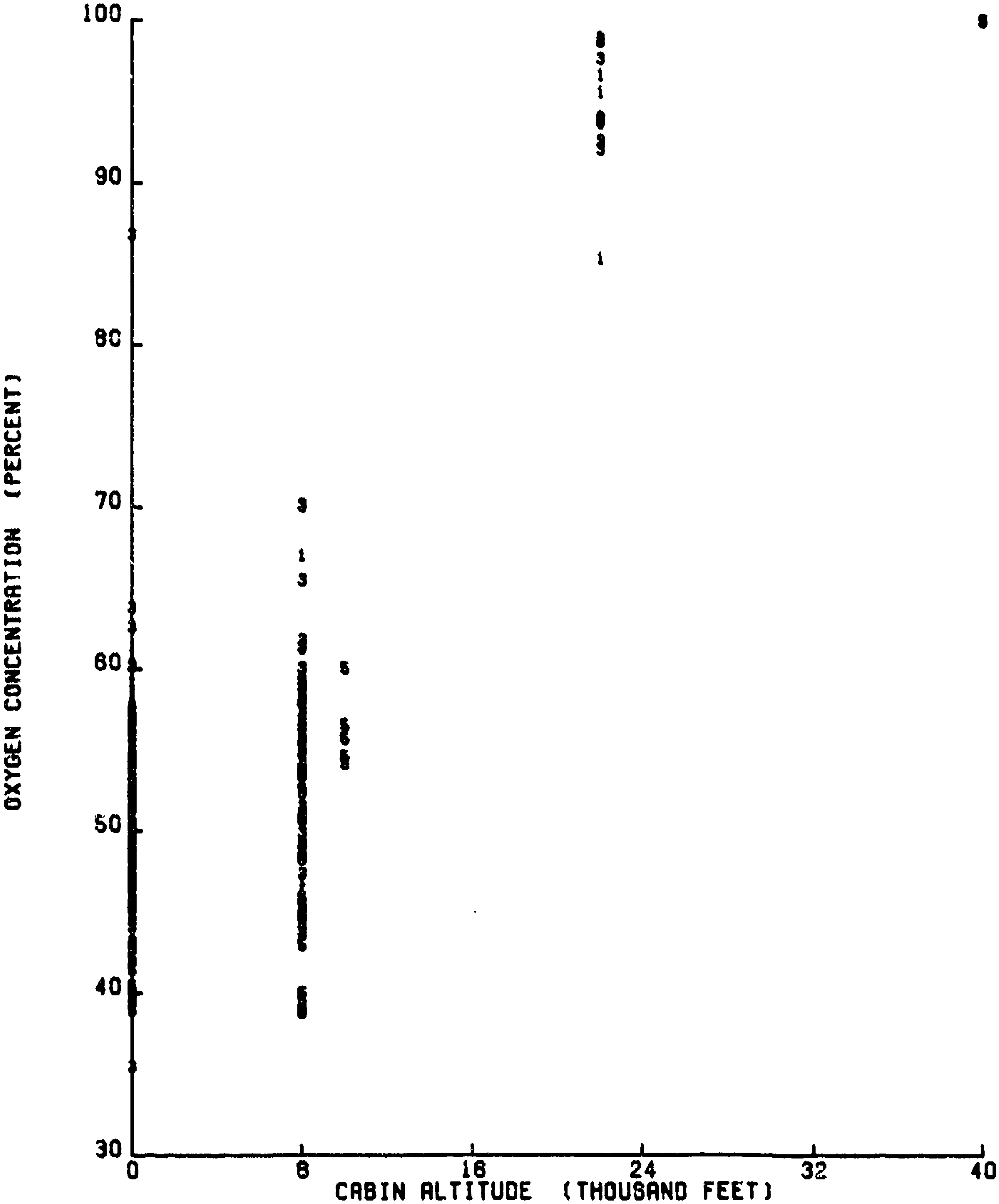

Figure 36. Human breathing: oxygen concentration vs cabin altitude with 40-psig inlet pressure, 80°C inlet temperature, and minute volumes of 0-20, 20-40, and 40-60 l/min. (1 = 0-20, 3 = 20-40, 5 = 40-60)

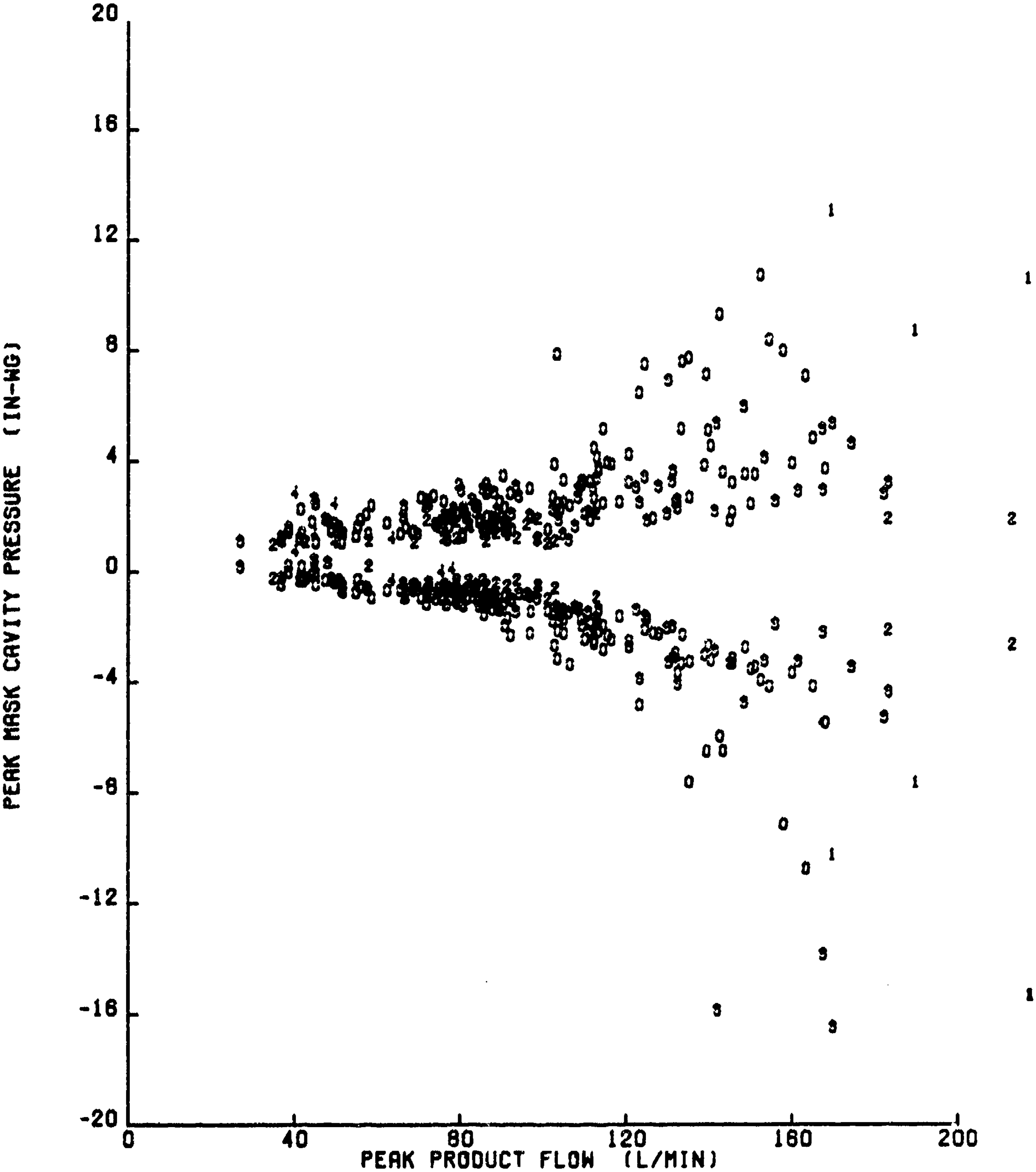

Figure 37. Human breathing: peak mask-cavity pressure vs peak product flow, with 40-psig inlet pressure and cabin altitude at ground level and 8K, 22K, and 40K feet. (0 = 8K, 2 = 22K, 4 = 40K)

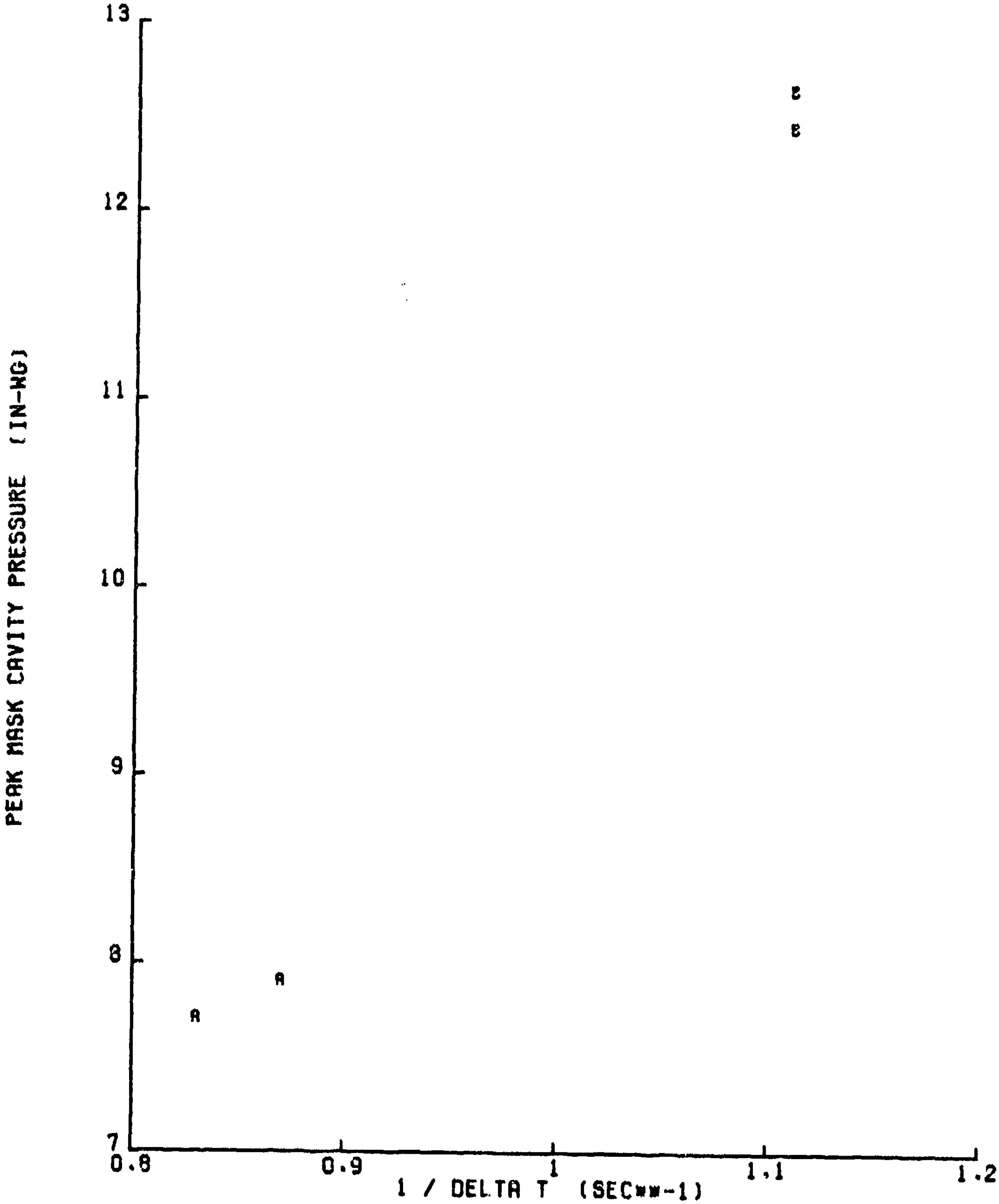

Figure 38. Human rapid decompression testing: peak mask-cavity pressure vs decompression time (1/delta t), with 40-psig inlet pressure and initial/final aircraft altitudes (K feet) of 8/23 and 16.8/40. (A = 8/23, B = 16.8/40)

Acceleration Testing

Four subjects were used for manned acceleration testing. All cockpit components were mounted in the centrifuge in the normal cockpit orientation. The concentrator was not installed in the centrifuge because of space limitations. The regulator was supplied with a bottled gas supply. The subjects were experienced centrifuge riders and were asked to perform M-1 straining maneuvers as necessary to prevent grey-out. Data from three subjects (Figs. 39-41) indicate that the higher G_Z loads required more forceful M-1 manuevers and created sharper and deeper inhalation patterns with high rates of change in flow that resulted in more negative mask-cavity pressures. This does not imply that higher G_Z loads affected the regulator. Comparing these data with human altitude data (Fig. 37) indicates that similar peak product flows produce similar minimum mask-cavity pressures. For example, acceleration testing of the first two subjects produced inspiratory mask pressures of -4 to -11 in-wg for product flows of approximately 170 l/min. Altitude testing produced inspiratory mask pressures of approximately -2 to -16 in-wg for similar product flows. The variation in mask pressures (more noticeable with altitude testing) was due to the variation in rate of change in flow. The fourth subject in acceleration testing was asked to breathe from the BOS supply. No difficulties were encountered, and mask-cavity pressures were well within specified limits.

RECOMMENDATIONS

During laboratory testing of the F-16A OBOGS, several items of interest were noted and will be reported here with the intent that they be considered as recommendations for future improvements. Some suggestions would not be costly to incorporate into future F-16 OBOGS. The ideas presented in this section are not necessarily afterthoughts: some suggested features were intentionally not incorporated in the flight demonstration program in order to minimize aircraft modifications.

Concentrator

Overall, the F-16A concentrator performed in a satisfactory manner. The most severe problem encountered in laboratory testing was failure of the rotary valve's electric-motor phasing capacitor. This nonstandard capacitor had to be replaced with a hermetically sealed capacitor rated at 115 VAC at 400 Hz. In this single-phase system, the capacitor induced a phase difference between the motor windings which produces torque. The capacitor could be eliminated by modifying the aircraft to make three-phase power available for the concentrator and by using a three-phase motor on the concentrator inlet valve. While an electrical modification of this type would be economical in the short term, longer term consideration should be given to replacing the electric motor with a pneumatic valve assembly to drive the rotary valve with bleed air pressure.

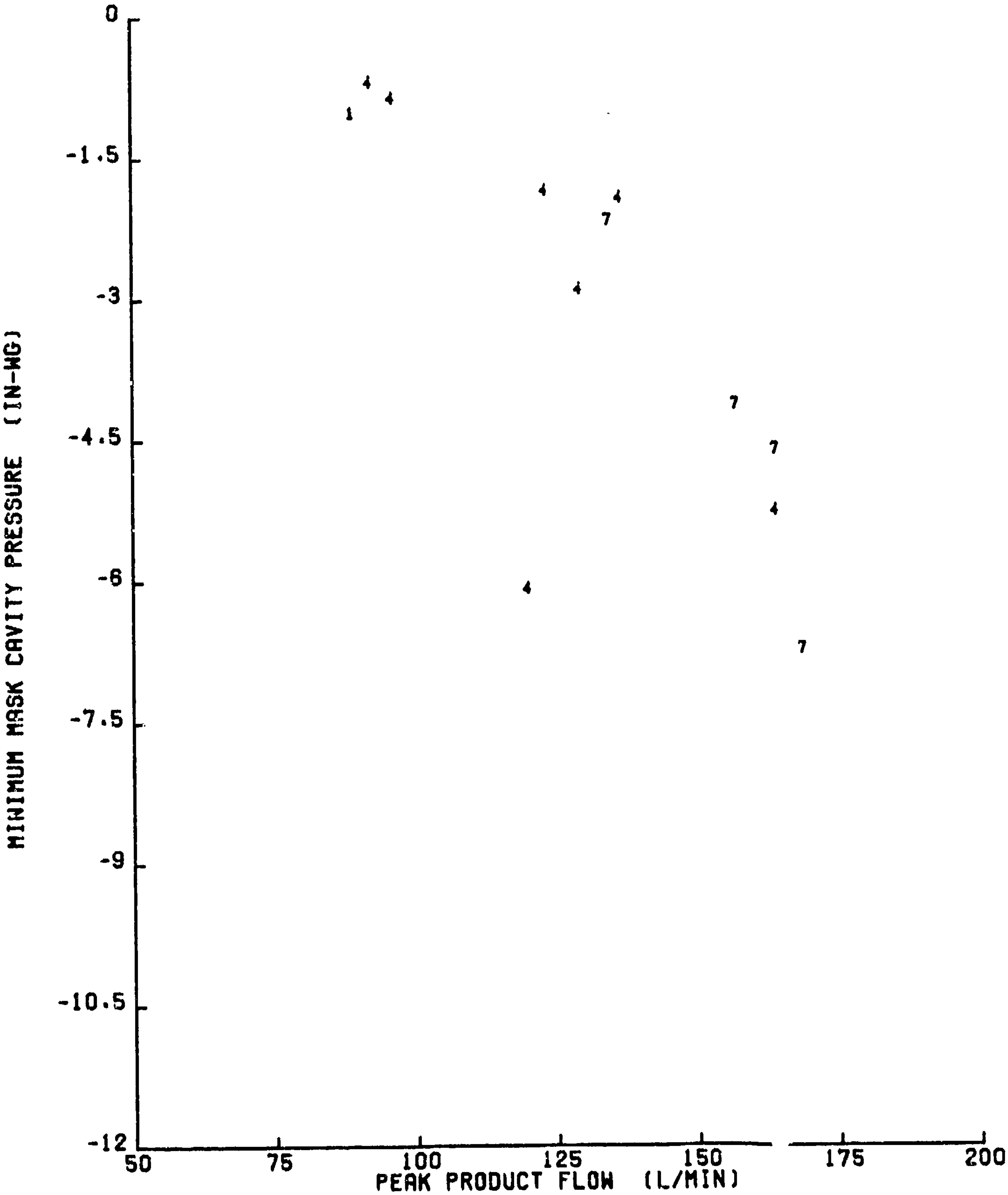

Figure 39. Human acceleration testing (subject No. 1) with G levels of 1, 4, and 7 G_z: minimum mask-cavity pressure vs peak product flow.

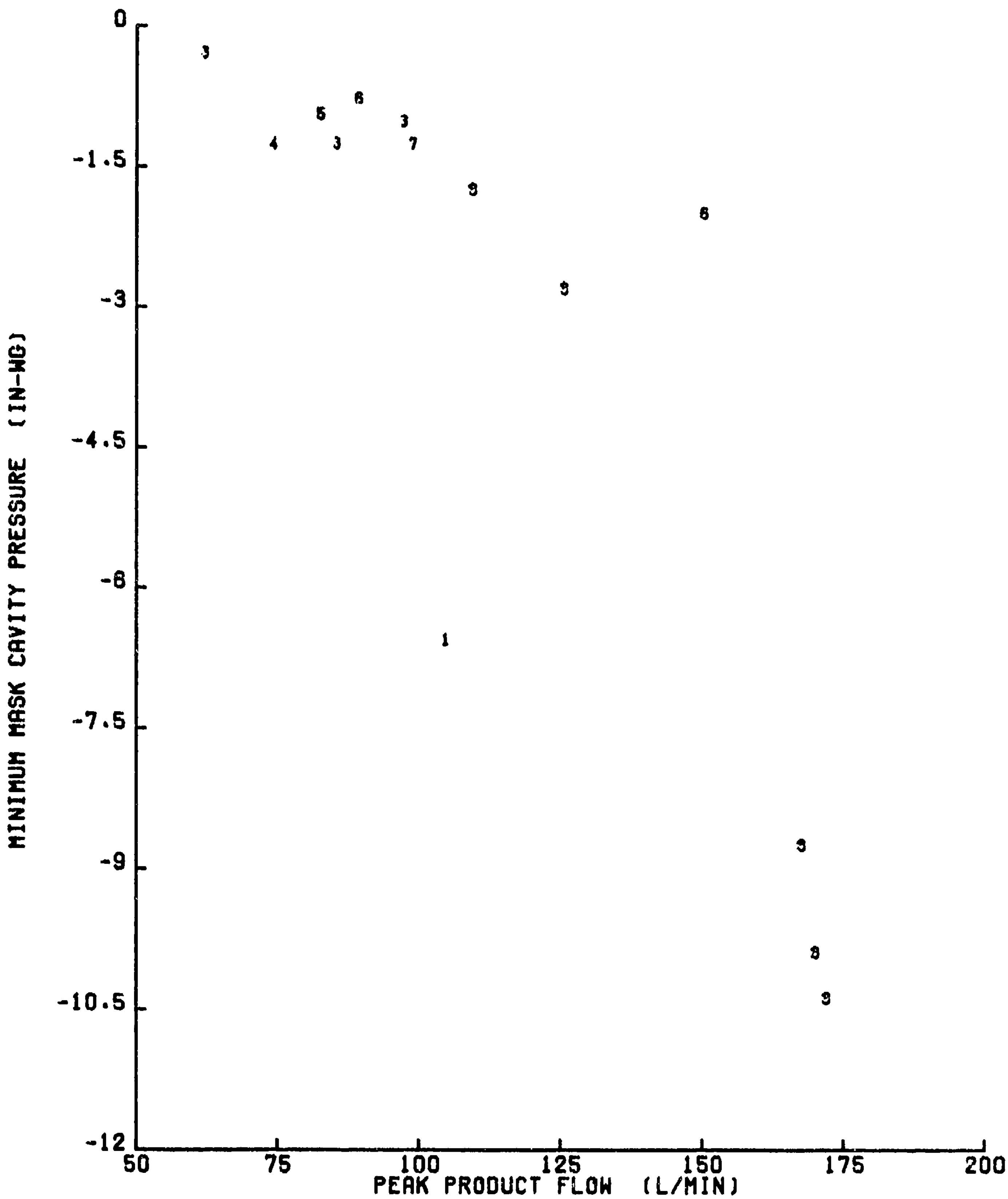

Figure 40. Human acceleration testing (subject No. 2) with G levels of 1, 3, 5, 6, 7, and 8 G_z: minimum mask-cavity pressure vs peak product flow.

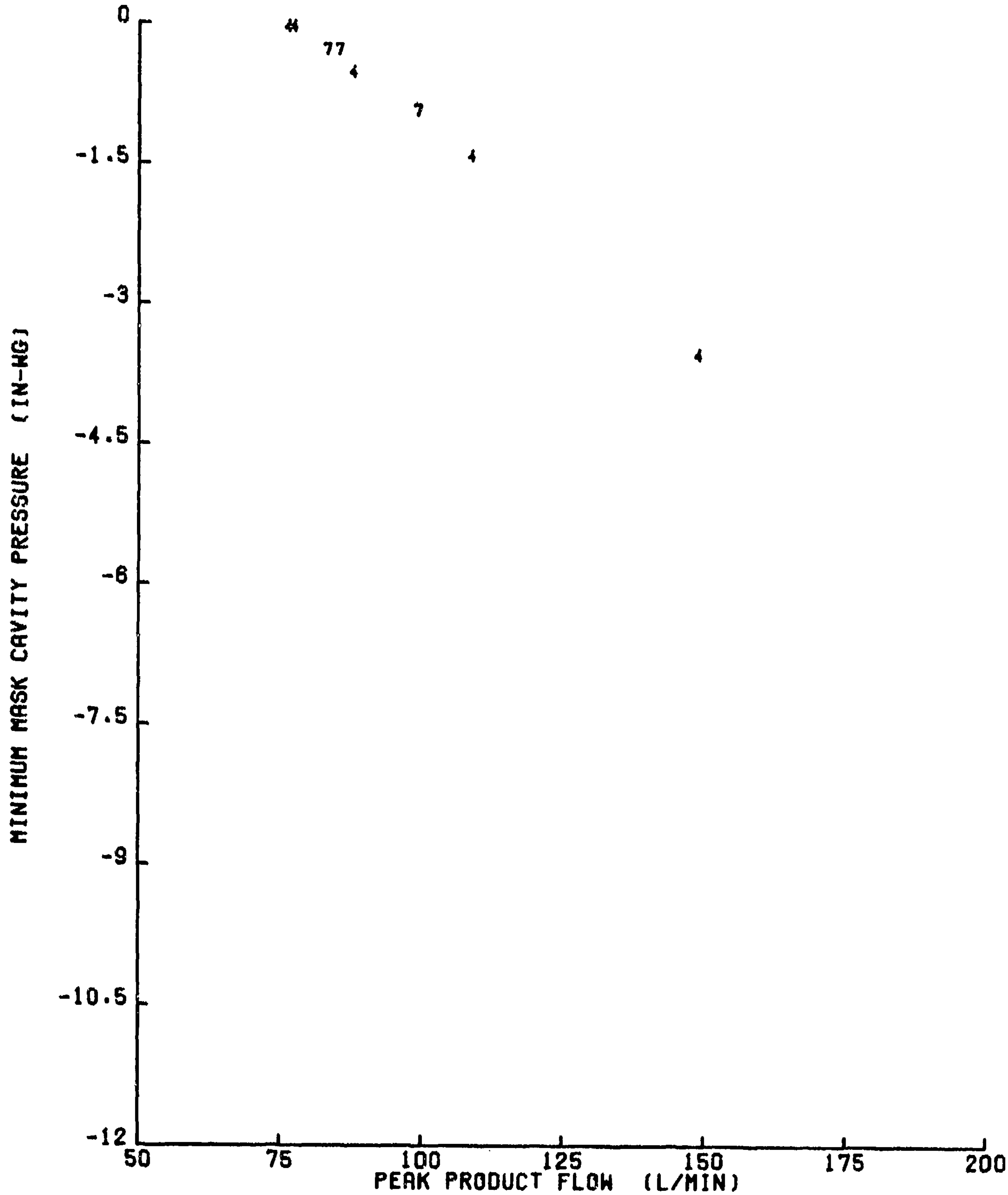

Figure 41. Human acceleration testing (subject No. 3) with G levels of 4 and 7 G_z: minimum mask-cavity pressure vs peak product flow.

The F-16A concentrator did not have a vent in the inlet air supply. Placing a vent in the inlet filter housing would allow any accumulation of moisture to escape overboard without entering the molecular sieve bed. This vent should be incorporated in future OBOGS concentrators to prevent water loading of the zeolite beds, which slowly depresses oxygen output. Coordination with the aircraft manufacturer can ascertain if a drain line should be added to dump moisture outside the aircraft.

The product gas line diameter was minimally acceptable for concentrator inlet pressures of 40 psig. The combination of low inlet pressure and high product-gas consumption may affect regulator performance by increasing breathing resistance. Increasing the product gas line diameter and/or adding a plenum in the cockpit, functionally located just prior to the regulator inlet port, can reduce this effect. This modification appears mandatory for the F-16B OBOGS to adequately supply two crewmembers.

Regulator

Regulator performance was satisfactory if concentrator inlet pressure remained at or above 40 psig. The test-mask feature delivered 17-in-wg pressure which was considered high by the test subjects and somewhat uncomfortable. Reduced test mask pressure (12 in-wg) would improve comfort without degrading the test procedure. Also, from an operational point of view, the system test button on the regulator package could be improved. The button must now be held fully depressed for 20 seconds to complete the test. When wearing gloves, the pilot cannot easily determine if the button is fully depressed, and 20 seconds is considered too long to dedicate for this test during preflight. The button should be replaced with a detent-type button which the pilot can lock in the test position. The pilot can then make other preflight checks and, when the indicator lights illuminate, can press the button again to return the system to normal. A lighted indicator might also be incorporated to verify switch position.

Another feature of the regulator that warrants improvement is the safety pressure. Now the pilot must turn the selector valve off to remove the mask without activating the BOS. This is an unsafe practice as the pilot could forget to turn the selector valve back to normal after redonning the mask. A provision on the regulator to turn off the safety pressure would allow the pilot to remove the mask inflight without activating the BOS. It is unrealistic to ask the pilot not to remove the mask inflight; consequently, a selectable safety pressure switch is needed on the regulator.

Controller

In the laboratory test program, the controller had to be adjusted several times to obtain the desired product gas composition. Adjusting the controller is an iterative trial-and-error process. Multiple-adjustment features would be desirable: one to adjust the ground-level flow rate; one to adjust the altitude at which the bleed flow begins to decrease; and one to adjust the rate of bleed flow shutdown. These features may be technically difficult to achieve, and some may not be necessary if the flight test program provides a realistic range of concentrator inlet parameters.

However, the ECS tap point, and thus concentrator inlet temperature, may change when the F-16 OBOGS goes into production. Also, the manufacturing process must maintain sufficient quality control in producing controller diaphragm springs to insure accurate oxygen concentration between controllers. Therefore, a provision on the controller to satisfactorily adjust the product gas composition is recommended.

The controller used in this system is an almost completely pneumatic device. Other approaches should be investigated. Perhaps using an electronic device or a mix between electronic and pneumatic devices may be advantageous.

Selector Valve

Interpreting the selector-valve switch positions was difficult. This valve could and probably should be simplified to avoid confusion for the user. Two possibilities are available.

The first method involves using a two-position selector valve switch and a weight-on-wheels (touchdown bypass) switch. The two positions on the selector valve would be labeled OBOG and BOS. In the BOS position, 100% oxygen would supply the mask at all times, including ground operations, as long as the BOS bottles were not depleted. In the OBOG position, concentrator product gas would supply the mask unless PO_2 fell below 195 mmHg, or regulator inlet pressure fell below 10 psig, or cabin altitude rose above 31,000 feet. On the ground, the weight-on-wheels switch would prevent the BOS from activating during a system test. With this method, as well as the next, a normally closed solenoid switch could be used downstream of the BOS bottles to prevent BOS leakage. The solenoid would need manual/nonelectrical override for ground or power-off operations.

The second and preferred method of simplifying the selector valve involves replacing the weight-on-wheels switch with a third position on the selector valve, called the BOS OFF position (Fig. 42). With the selector valve in the OFF position, the BOS would be disengaged, thus allowing the system test to be activated on the ground without consuming BOS gas. The OFF should be a push-to-turn position to prevent its inadvertent use in flight.

In the current OBOG position the selector valve will not automatically switch the BOS if PO_2 falls below 195 mmHg. In this case if the pilot does not switch the selector valve to AUTO or BOS, and if PO_2 falls significantly below 195 mmHg, the pilot may become hypoxic. In other switch positions the system automatically switches to BOS; therefore, to be consistent, the selector valve should switch to BOS if PO_2 falls below 195 mmHg in the OBOG position.

As with the controller, perhaps a mix of electronic and pneumatic devices may simplify construction of the selector valve.

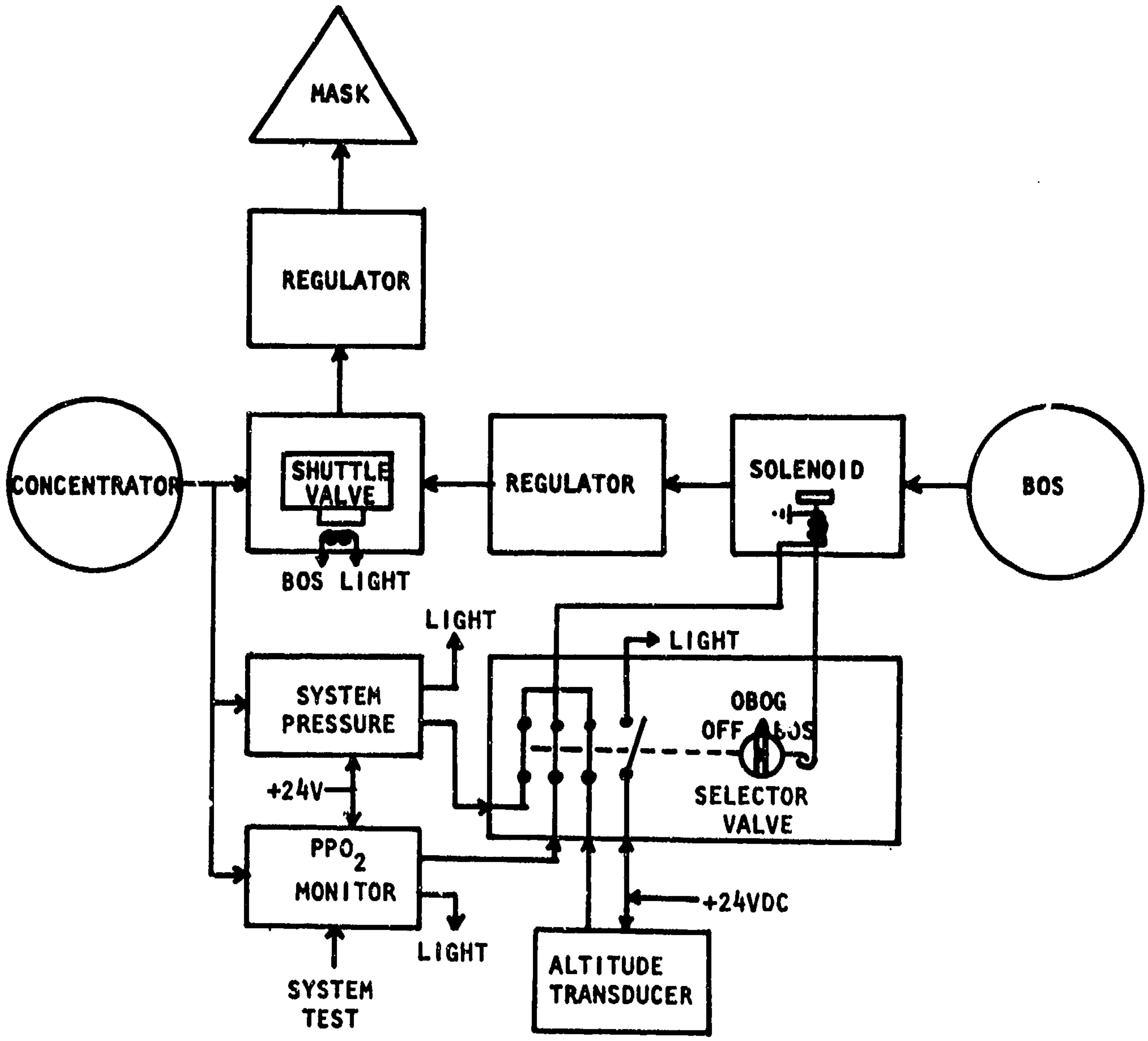

Figure 42. Proposed OBOG system.

Indicators

Several shortcomings were noted with the indicator lights. First, in conjunction with the selector valve nomenclature, is the interpretation of the indicators. The meaning of an illuminated indicator light is difficult to completely translate (reference Table 1). The light on the selector valve should be known as a BOS light and should illuminate only when 100% oxygen is supplied to the mask. The BOS light should not illuminate just because the selector valve is in the BOS position, i.e., when the selector valve is at BOS but the BOS bottle is empty. Also, if 100% oxygen is being supplied to the pilot, the light must always illuminate (contrary to the present condition when the selector valve is in the OBOG position and cabin altitude is above 31,000 feet). A magnetic switch placed on the shuttle valve to sense BOS flow could activate the BOS light. Also, the BOS light on the selector valve needs to be relocated. The selector valve is located behind the control stick, so the light is not visible to the pilot; it also interferes with the knob on the selector valve. Mounting the BOS light directly above the BOS pressure gauge would direct the pilot's attention toward BOS pressure when the light illuminates. This would reinforce the need to monitor BOS pressure when it is in use. The F-16 instrument panel has ample room for the light in this position.

The OXY LOW light should be relabeled as OBOG, to indicate an OBOG problem. This light now illuminates due to low PO_2 or low regulator inlet pressure. A single light cannot indicate which malfunction exists; perhaps two lights may be necessary.

During the press-to-test system, all indicators should illuminate.

Miscellaneous

As the flight test program proceeds, several other recommendations may become apparent. Any change must not interfere with the integrity of the BOS. The BOS must be made leakproof, which may require hard line tubing in lieu of flexible tubing from the BOS manifold to the selector valve. The selector valve must be able to seal the BOS and preclude its frequent servicing.

CONCLUSIONS

The F-16A OBOGS is a successful system which promises to overcome all lox shortcomings--the hazards of storing and handling, the expense and logistics inherent with lox, the cost of stockpiling and replacing lox convertors and ground carts, the unacceptable service delays which increase turnaround time in wartime environments, and possible limits in mission duration due to the limited onboard quantity of lox.

Laboratory testing proved the equipment, built by Clifton Precision according to USAFSAM specifications, to be adequate for flight testing.

Adoption of the laboratory test and flight test recommendations will ensure that OBOGS will further enhance the mission of the F-16 aircraft.

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFMC)
BROOKS AIR FORCE BASE, TEXAS

ERRATA. AD-B076 849

5 Feb 97

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER (DTIC)

FROM: AL/XPPL
2509 Kennedy Circle
Brooks AFB TX 78235-5118

SUBJECT: Change in Distribution Statement for USAFSAM-TR-~~93~~ 83-27, AD-B076 849

1. The document listed above has been reviewed by the Public Affairs Office, Brooks Air Force Base, Texas and has been changed from limited distribution to distribution A, unlimited release (see attachment, AL/XPPL 21 Jan 97 Ltr).

2. Please change the distribution statement at DTIC and make available to NTIS.

Judy A. Bryant
JUDY A. BRYANT
AL STINFO OFFICER

Attachment:
AL/XPPL 21 Jan 97 Ltr

Completed
22 mar 2000
B.W.

DEPARTMENT OF THE AIR FORCE
ARMSTRONG LABORATORY (AFMC)
BROOKS AIR FORCE BASE, TEXAS

21 Jan 97

MEMORANDUM FOR AL/XP (Dr. Miller)
AL/XPPL
IN TURN

FROM: AL/XPPL

SUBJECT: AL/AO Request for Release of Document to Czech Republic

1. AL/AO is requesting to release the attached report (USAFSAM-TR-83-27 to the Czech Republic. This report has a Distribution limitation (as of 1983); however, the information may no longer need protection since it is 14 years. At the time of its publication, Capt Thomas Horch was project engineer and Dr. Richard L. Miller was his supervisor.

2. As former supervisor of the original project engineer, request your review of this report and recommendation for its release to the Czech republic. Request you also review for possible downgrading from "Unclassified-Limited" (export controlled) to "Approval for public release." If you wish to downgrade it, we will send it to Public Affairs for review and approval. Please try to complete your review and return by **7 Feb 97**.

3. If you have questions, please call--ext 5495. Thank you,

Judy A. Bryant
JUDY A. BRYANT
Foreign Disclosure Officer

Atch:
USAFSAM-TR-83-27

APPROVED FOR RELEASE TO CZECH REPUBLIC or **NOT RELEASABLE**

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RICHARD L. MILLER, PhD
Deputy Director, Plans

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Deputy Director, Plans

(You can approve both if you wish.)

* (HSC/PA Approval Authority)

97-034
(PA Approval #